THE CITY OF SAN DIEGO

Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall 2010

City of San Diego
Ocean Monitoring Program

Public Utilities Department
Environmental Monitoring and Technical Services Division

THE CITY OF SAN DIEGO

June 30, 2011

Mr. David Gibson, Executive Officer
Regional Water Quality Control Board
San Diego Region
9174 Sky Park Court, Suite 100
San Diego, CA 92123

Attention: POTW Compliance Unit

Dear Sir:

Enclosed on CD is the 2010 Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall as required per NPDES Permit No. CA0107409, Order No. R9-2009-0001. This report contains data summaries, analyses and interpretations of the various portions of the ocean monitoring program, including oceanographic conditions, water quality, sediment characteristics, macrobenthic communities, demersal fishes and megabenthic invertebrates, and bioaccumulation of contaminants in fish tissues.

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, I certify that the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Sincerely,

Steve Meyer
Deputy Public Utilities Director

SM/tds

Enclosure: CD containing PDF file of this report

cc: U.S. Environmental Protection Agency, Region 9
Department of Environmental Health, San Diego County
Division of Water Quality, State Resources Control Board

DIVERSITY
BRINGS US ALL TOGETHER

Environmental Monitoring and Technical Services Division • Public Utilities
2392 Kincaid Road • San Diego, CA 92101-0811
Tel (619) 758-2300 Fax (619) 758-2309

Annual Receiving Waters Monitoring Report
for the
Point Loma Ocean Outfall

2010

Prepared by:

City of San Diego
Ocean Monitoring Program
Public Utilities Department
Environmental Monitoring and Technical Services Division

June 2011

Timothy D. Stebbins, Editor
Ami K. Latker, Managing Editor

Table of Contents

Table of Contents (*continued*)

Table of Contents (*continued*)

List of Tables

Table of Contents (*continued*)

List of Figures

Table of Contents (*continued*)

List of Figures (*continued*)

List of Boxes

List of Appendices

Table of Contents (*continued*)

List of Appendices (*continued*)

Acronyms and Abbreviations

ADCP	Acoustic Doppler Current Profiler
ANOSIM	Analysis of Similarity
APHA	American Public Health Association
APT	Advanced Primary Treatment
AUV	Automated Underwater Vehicle
BACIP	Before-After-Control-Impact-Paired
BOD	Biochemical Oxygen Demand
BRI	Benthic Response Index
χ^2	Pearson's Chi-square Analyses test statistic
CCS	California Current System
CDHS	California State Department of Health Services
CFU	Colony Forming Units
cm	centimeter
CSDMML	City of San Diego Marine Microbiology Laboratory
CTD	Conductivity, Temperature, Depth instrument
DDT	Dichlorodiphenyltrichloroethane
df	degrees of freedom
DO	Dissolved Oxygen
ELAP	Environmental Laboratory Accreditation Program
EMAP	Environmental Monitoring and Assessment Program
EMTS	Environmental Monitoring and Technical Services
ERL	Effects Range Low
ERM	Effects Range Median
F:T	Fecal to Total coliform ratio
FIB	Fecal Indicator Bacteria
ft	feet
FTR	Fecal to Total coliform Ratio criterion
g	gram
H'	Shannon diversity index
HCB	Hexachlorobenzene
HCH	Hexachlorocylclohexane
IGODS	Interactive Geographical Ocean Data System
in	inches
IR	Infrared
IWTP	International Wastewater Treament Plant
J'	Pielou's evenness index
kg	kilogram
km	kilometer
km^2	square kilometer
L	Liter
m	meter
m^2	square meter
MDL	Method Detection Limit
nMDS	Non-metric Multidimensional Scaling
mg	milligram

Acronyms and Abbreviations (*continued*)

mgd	millions of gallons per day
ml	maximum length
mL	milliliter
mm	millimeter
MODIS	Moderate Resolution Imaging Spectroradiometer
MRP	Monitoring and Reporting Program
mt	metric ton
n	sample size
N	number of observations used in a Chi-square analysis
ng	nanograms
no.	number
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollution Discharge Elimination System
NWS	National Weather Service
O&G	Oil and Grease
OEHHA	California Office of Environmental Health Hazard Assessment
OI	Ocean Imaging
p	probability
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyls
PDO	Pacific Decadal Oscillation
pH	Acidity/Alkalinity value
PLOO	Point Loma Ocean Outfall
PLWTP	Point Loma Wastewater Treatment Plant
ppb	parts per billion
ppm	parts per million
ppt	parts per trillion
PRIMER	Plymouth Routines in Multivariate Ecological Research
psu	practical salinity units
r	Pearson correlation coefficient
r_s	Spearman rank correlation coefficient
ROV	Remotely Operated Vehicle
RWQCB	Regional Water Quiality Control Board
SABWTP	San Antonio de los Buenos Wastewater Treatment Plant
SBOO	South Bay Ocean Outfall
SBWRP	South Bay Water Reclamation Plant
SCB	Southern Califonia Bight
SCBPP	Southern California Bight Pilot Project
SD	Standard Deviation
SIMPER	Similarity Percentages Routine
SIMPROF	Similarity Profile Analysis
SIO	Scripps Institution of Oceanography
sp	species (singular)
spp	species (plural)
SSM	Sub-surface Salinity Minimum

Acronyms and Abbreviations (*continued*)

SWRCB	Califonia State Water Resources Control Board
tDDT	total DDT
TN	Total Nitrogen
TOC	Total Organic Carbon
tPAH	total PAH
tPCB	total PCB
TSS	Total Suspended Solids
TVS	Total Volatile Solids
USEPA	United States Environmental Protection Agency
USFDA	United States Food and Drug Administration
USGS	United States Geological Survey
USIBWC	United States International Boundary and Water Commission
wt	weight
yr	year
ZID	Zone of Initial Dilution
α	alpha, the probability of creating a type I error
μg	micrograms
π	summed absolute distances test statistic

This page intentionally left blank

Production Credits and Acknowledgements

Technical Editors:
T. Stebbins, A. Latker, P. Vroom

Production Editors:
E. Moore, N. Haring, M. Nelson, P. Vroom, R. Gartman, A. Davenport

GIS Graphics:
M. Kasuya, D. Olson, J. Pettis Schallert

Cover Photo:
Early morning view of the "New" Point Loma Lighthouse constructed in 1891 and located at the southern tip of Point Loma, San Diego. Photo by Eliza Moore.

Acknowledgments:
We are grateful to the personnel of the City's Marine Biology, Marine Microbiology, and Wastewater Chemistry Services Laboratories for their assistance in the collection and/or processing of all samples, and for discussions of the results. The completion of this report would not have been possible without their continued efforts and contributions. We would especially like to thank A. Davenport, W. Enright, M. Kasuya, M. Nelson, D. Olson, L. Othman, J. Pettis Schallert, R. Velarde, and L. Wiborg for their critical reviews of various chapters of this report. We would also like to thank Drs. E. Parnell, L. Rasmussen and E. Terrill of the Scripps Institution of Oceanography for their advice and assistance. Complete staff listings for the above labs and additional details concerning relevant QA/QC activities for the receiving waters monitoring data reported herein are available online in the 2010 EMTS Division Laboratory Quality Assurance Report (www.sandiego.gov/mwwd/environment/reports.shtml).

How to cite this document:
City of San Diego. (2011). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2010. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

This page intentionally left blank

Executive Summary

Executive Summary

The City of San Diego (City) conducts extensive ocean monitoring to evaluate potential environmental effects from the discharge of treated wastewater to the Pacific Ocean via the Point Ocean Outfall (PLOO). The data collected are used to determine compliance with receiving water conditions as specified in the National Pollution Discharge Elimination System (NPDES) permit for the City's Point Loma Wastewater Treatment Plant (PLWTP).

The primary objectives of the Point Loma ocean monitoring program are to: (a) measure compliance with NPDES permit requirements and California Ocean Plan (Ocean Plan) standards, (b) monitor changes in ocean conditions over space and time, and (c) assess any impacts of wastewater discharge or other man-made or natural influences on the local marine environment, including effects on water quality, sediment conditions and marine life. The study area encompasses approximately 184 km^2 of coastal waters centered around the PLOO discharge site, which is located approximately 7.2 km offshore of the PLWTP at a depth of nearly 100 m. Shoreline monitoring extends from Mission Beach southward to the tip of Point Loma, while regular offshore monitoring occurs in an adjacent area at sites ranging from about 9 to 116 m in depth.

The City conducts other types of studies in addition to its regular monitoring for Point Loma that are useful for evaluating patterns and trends over time or that span broader geographic regions, thus providing additional information to help distinguish reference areas from sites that may be affected by anthropogenic influences. For example, prior to the initiation of wastewater discharge at the present deepwater location in late 1993, the City conducted a 2½-year baseline study designed to characterize background environmental conditions in the Point Loma region. Additionally, a broader geographic survey of benthic conditions is typically conducted during the summer each year at sites ranging from northern San Diego County (around La Jolla–Del Mar) south to the USA/Mexico international border as part of the monitoring program for the South Bay Ocean Outfall. Results of the 2010 regional survey are included in the annual receiving waters monitoring report for the South Bay outfall region. The City also collaborates with other organizations on larger-scale, regional monitoring projects that span the entire Southern California Bight (SCB). These bight-wide surveys include the original pilot project in 1994, and subsequent Bight'98, Bight'03, and Bight'08 projects (see Chapter 1).

The receiving waters monitoring activities for the Point Loma region are separated into several major components, which are organized into seven chapters in this report. Chapter 1 presents a general introduction and overview of the Point Loma ocean monitoring program, as well as background information on wastewater treatment processes at the PLWTP, including the initiation of chlorination in late 2008. In Chapter 2, data regarding various physical and chemical parameters are evaluated to characterize oceanographic conditions and water mass transport potential for the region. Chapter 3 presents the results of water quality monitoring conducted along the shore and in local coastal waters, including measurements of fecal indicator bacteria (FIB) to determine compliance with Ocean Plan water-contact standards. Assessments of benthic sediment quality and the status of soft-bottom macrobenthic invertebrate communities are presented in Chapters 4 and 5, respectively. Chapter 6 presents the results of trawling activities designed to monitor communities of demersal (bottom dwelling) fishes and megabenthic invertebrates. Bioaccumulation assessments to determine if contaminants are present in the tissues of local fishes captured via trawls or by hook and line are presented in Chapter 7. In addition to the above activities, the City supports other projects relevant to assessing the quality of ocean waters in the region. One such project involves aerial and satellite imaging studies of the San Diego/ Tijuana coastal regions. The results of these remote sensing efforts conducted in 2010 are incorporated herein into discussions and interpretations of oceanographic and water quality conditions (see Chapters 2 and 3).

This report focuses on the results and conclusions of all ocean monitoring activities conducted in the Point Loma region from January 1, 2010 through December 31, 2010. An overview and summary of the main findings for each of the major components of the program are included below.

Oceanographic Conditions

The Point Loma outfall region was characterized by typical oceanographic conditions in 2010. This included seasonal patterns such as coastal upwelling with corresponding phytoplankton blooms in the spring and summer, maximum stratification (layering) of the water column in mid-summer, and reduced stratification during the winter and fall. Remote sensing observations revealed no visible evidence of the wastewater plume reaching surface waters, even during the winter and fall months when the water column was only weakly stratified. This is consistent with results from the bacteriological surveys conducted during the year (see below). There was also no evidence that the wastewater plume reached nearshore recreational waters or the shoreline during the year. For example, analysis of current meter data indicated that current conditions in 2010 were not conducive to shoreward transport of the plume. Instead, these results showed currents moving predominantly offshore throughout the year in mostly north/northwest or south/southeast directions. Overall, the observed variations in ocean conditions off Point Loma this past year were consistent with expectations due to typical seasonal cycles, as well as with changes in larger patterns reported for the California Current System. Together, this suggests that other factors such as the upwelling of cool, nutrient-rich deep ocean waters, the occurrence of associated plankton blooms, and the effects of large-scale oceanographic events may best explain most of the temporal and spatial variability observed in the region.

Water Quality

There was no evidence that wastewater discharged to the ocean via the PLOO reached surface or near-shore recreational waters in 2010. For example, the wastewater plume was not detected in any aerial and satellite imagery taken during the year. Although elevated counts for fecal indicator bacteria (FIB) such as total coliforms, fecal coliforms and enterococcus were occasionally detected along the shore and at a few nearshore stations, concentrations of these bacteria tended to be relatively low overall. Over the years, elevated FIBs detected at the shore and kelp bed stations have tended to be associated with rainfall events, heavy recreational use, or the presence of seabirds or decaying kelp and surfgrass. During 2010, most high counts were limited to instances when contamination was most likely the result of heavy rainfall that increased outflows and the dispersion of associated turbidity plumes from the San Diego River, San Diego Bay, and even the Tijuana River. The elevated FIB counts that could likely be attributable to wastewater discharge were limited to offshore waters at depths of 60 m or below. This finding supports previous water quality analyses for the region, which have indicated that the PLOO wastefield typically remains offshore and submerged in deep waters.

Bacterial compliance levels were summarized as the number of days that each of the shore, kelp bed and offshore stations within State waters exceeded various Ocean Plan water-contact standards during each month. Due to regulatory changes that became effective August 1, 2010, compliance was assessed using the standards specified in the 2001 Ocean Plan for samples collected from January 1 through July 31, 2010, whereas samples collected after August 1, 2010 were assessed using 2005 Ocean Plan standards. Compliance with these standards was very high throughout the year with an overall compliance rate of 99.7% over all stations.

Additionally, ammonia (sampled as nitrogen) was detected infrequently and at only very low levels, throughout the kelp bed and offshore areas, and there was no correspondence between ammonia concentrations and FIB levels.

Sediment Conditions

Ocean sediments at stations surrounding the PLOO in 2010 were composed primarily of fine sands and coarse silt, which is similar to patterns seen in previous years. Differences in the particle size composition of Point Loma sediments are likely affected by both anthropogenic and natural influences, including outfall construction materials, offshore disposal of dredged materials, multiple geological origins of different sediment types, and recent deposits of detrital materials. There was no evident relationship between sediment composition and proximity to the outfall discharge site.

Overall, sediment quality at the PLOO monitoring sites was similar in 2010 to previous years, and there were few clear patterns in contaminant accumulation relative to the discharge site. The only exceptions were slightly elevated sulfide and biochemical oxygen demand (BOD) levels at a few stations located within about 300 m of the outfall. Sediment concentrations of the various trace metals, organic loading indicators, pesticides (e.g., DDT), PCBs and PAHs remained within the typical range of variability for San Diego and other coastal areas of southern California. The potential for degradation by any of the detected chemical contaminants was further evaluated by using the Effects Range Low (ERL) and Effects Range Median (ERM) sediment quality guidelines as benchmarks. Only two samples contained levels of DDT that exceeded available ERLs, and none of the contaminants detected in 2010 exceeded their ERM. Additionally, the highest concentrations of several contaminants occurred at sites relatively distant from the outfall. For example, concentrations of several organic indicators and trace metals were highest in sediments from the northern-most stations. In contrast, several pesticides, PCBs, and PAHs were detected mostly in sediments from stations located south of the outfall. This latter pattern is consistent with other studies that have suggested that sediment contamination at these and other southern stations off San Diego is most likely due to misplaced deposits (short dumps) of dredged materials originally destined for the LA-5 disposal site located southwest of the PLOO discharge site.

Macrobenthic Communities

Benthic macrofaunal communities in the PLOO region in 2010 were dominated by polychaete worm and ophiuroid (brittle star) assemblages in terms of abundance, with few major changes in population numbers of these animals having occurred since monitoring began in 1991. Additionally, polychaetes were extremely diverse across the region. Although invertebrate assemblages at each survey site contained a similar mix of species, the relative abundance of these species varied among sites, likely because of sediment heterogeneity. The brittle star *Amphiodia urtica* was the most abundant species across the region, while the bivalve *Axinopsida serricata* was the second most abundant benthic invertebrate. Overall, the invertebrate assemblages documented were typical of those occurring in other mid-depth areas of the SCB where similar, relatively fine sediment habitats occur.

Benthic invertebrate assemblages off Point Loma have changed in a relatively small, localized region within ~300 m of the outfall diffuser legs as would be expected near large ocean outfalls. For example, some descriptors of benthic community structure (e.g., infaunal abundance, species diversity) or populations of indicator species (e.g., *A. urtica*) have indicated shifts in species composition or abundance over time between reference areas and sites located nearest the outfall. However, despite these changes, results for the benthic response index (BRI) remain characteristic of undisturbed sediments. In addition, documented changes in macrofaunal community structure near the outfall in 2010 were similar in magnitude to those reported previously for the PLOO and elsewhere off southern

California. Overall, macrofaunal assemblages in the region remain similar to those observed prior to wastewater discharge and to natural indigenous communities characteristic of similar habitats on the southern California continental shelf. There was no evidence that wastewater discharge has caused degradation of the marine benthos in the PLOO monitoring region.

Demersal Fishes and Megabenthic Invertebrates

Pacific sanddabs continued to dominate fish assemblages surrounding the PLOO during 2010 as they have for many years. This species occurred at all stations and accounted for 42% of the total fish catch. Other characteristic, but less abundant fishes included California lizardfish, halfbanded rockfish, longspine combfish, plainfin midshipman, pink seaperch, yellowchin sculpin, Dover sole, stripetail rockfish, shortspine combfish, English sole, greenstriped rockfish, and bigmouth sole. Although the overall composition and structure of the local fish assemblages varied among stations, most differences were due to fluctuations in Pacific sanddab populations.

Assemblages of relatively large (megabenthic) trawl-caught invertebrates in the region were similarly dominated by a single species, the white sea urchin *Lytechinus pictus*. Consequently, variations in megabenthic community structure off Point Loma generally reflect changes in the abundance of this urchin, although other species such as the brittle star *Ophiura luetkenii*, the sea pen *Acanthoptilum* sp, the sea slug *Pleurobranchaea californica*, the sea cucumber *Parastichopus californicus*, the sea stars *Astropecten verrilli* and *Luidia foliolata*, and the octopus *Octopus rubescens* also contributed to community differences.

Overall, the 2010 trawl survey results indicate that trawl-caught fish and invertebrate communities in the region are unaffected by wastewater discharge. Although highly variable, patterns in the abundance and distribution of these organisms were similar at stations located near the outfall and farther away, suggesting a lack of significant anthropogenic influence. Instead, changes in these communities appear to be more likely due to natural factors such as seasonal water temperature fluctuations or large-scale oceanographic events (e.g., El Niño), as well as to the mobile nature of many species.

The types and frequencies of external health problems for fish can be important indicators of environmental impact. Examinations of trawl-caught fishes for evidence of disease (e.g., tumors, fin erosion, skin lesions) or the presence of ectoparasites showed that local fish populations remain healthy. For example, external parasites and other external abnormalities occurred in less than 1% of the fishes collected in the Point Loma region during 2010. Overall, these results were consistent with findings from previous years and provided no indication of outfall effects.

Contaminants in Fish Tissues

There was no clear evidence to suggest that tissue contaminant loads in fishes captured at the PLOO monitoring sites were affected by the discharge of wastewater in 2010. Although several metals, three pesticides, and various PCB congeners were detected in liver tissues from flatfish and muscle tissues from rockfish sampled in the region, these contaminants were found in fishes distributed widely among stations and showed no patterns that could be attributed to wastewater discharge. Further, all contaminant values were within the range of those reported previously for southern California fishes. Finally, while some muscle tissue samples from sport fishes collected off Point Loma had arsenic and selenium concentrations above the median international standard for shellfish, and some samples had mercury and PCB levels that exceeded OEHHA fish contaminant goals, concentrations of mercury and DDT were still below USFDA human consumption limits.

The occurrence of both trace metals and chlorinated hydrocarbons in the tissues of Point Loma fishes may be due to many factors, including the widespread distribution of many contaminants in coastal sediments off southern California. Other factors that affect the bioaccumulation and distribution of contaminants in local fishes include the different physiologies and life history traits of various species. Exposure to contaminants can vary greatly between species and even among individuals of the same species depending on migration habits. For example, fishes may be exposed to pollutants in a highly contaminated area and then move into a region that is less contaminated. This is of particular concern for fishes collected in the vicinity of the PLOO, as there are many other point and non-point sources in the region that may contribute to contamination.

Conclusions

The findings and conclusions for the 2010 ocean monitoring effort for the Point Loma outfall region were consistent with previous years. Overall, there were limited impacts to local receiving waters, benthic sediments, and marine invertebrate and fish communities. There was no evidence that the PLOO wastefield reached surface waters or nearshore recreational areas during the year. Although elevated bacterial levels did occur along the shore and at various kelp bed sites, such instances were largely associated with higher rainfall during the wet season and not to shoreward transport of the wastewater plume. There were also no outfall related patterns in sediment contaminant distributions, or in differences between the various invertebrate and fish assemblages. The general lack of disease symptoms in local fish populations, as well as the low level of contaminants detected in fish tissues, was also indicative of a healthy marine environment. Finally, benthic habitats in the region remain in good condition similar to much of the Southern California Bight mainland shelf.

This page intentionally left blank

Chapter 1
General Introduction

Chapter 1. General Introduction

Treated effluent from the City of San Diego's Point Loma Wastewater Treatment Plant (PLWTP) is presently discharged to the Pacific Ocean through the Point Loma Ocean Outfall (PLOO) according to requirements set forth in National Pollutant Discharge Elimination System (NPDES) Permit No. CA0107409, Order No. R9-2009-0001. This Order was adopted by the San Diego Regional Water Quality Control Board (RWQCB) on June 10, 2009 and became effective August 1, 2010. The Monitoring and Reporting Program (MRP) included in this order defines the requirements for ambient receiving waters monitoring in the region off Point Loma, San Diego. This includes sampling design and frequency, compliance criteria, types of laboratory analyses, and data analysis and reporting guidelines. The main objectives of the Point Loma ocean monitoring program are to provide data that satisfy NPDES permit requirements, demonstrate compliance with California Ocean Plan (Ocean Plan) provisions, detect dispersion and transport of the waste field (plume), and identify any environmental changes that may be associated with wastewater discharge via the outfall.

Background

The City of San Diego (City) began operation of the PLWTP and original ocean outfall off Point Loma in 1963, at which time treated effluent (wastewater) was discharged approximately 3.9 km offshore at a depth of about 60 m. From 1963 to 1985, the plant operated as a primary treatment facility, removing approximately 60% of the total suspended solids (TSS) by gravity separation. The City began upgrading the process to advanced primary treatment (APT) in mid-1985, with full APT status being achieved by July of 1986. This improvement involved the addition of chemical coagulation to the treatment process, which resulted in an increased TSS removal of about 75%. Since 1986, treatment has been further enhanced with the addition of several more sedimentation basins, expanded aerated grit removal, and refinements in chemical treatment. These enhancements have resulted in lower mass emissions from the plant. TSS removals are now consistently greater than the 80% permit requirement. Finally, the City began testing disinfection of PLWTP effluent using a sodium hypochlorite solution in September 2008 following adoption of Addendum No. 2 to previous Order No. R9-2002 0025. These chlorination activities continued throughout 2010.

Additional changes occurred in the early 1990s when the outfall was extended approximately 3.3 km further offshore in order to prevent intrusion of the wastewater plume into nearshore waters and to increase compliance with Ocean Plan standards for water-contact sports areas. Construction of the outfall extension was completed in November 1993, at which time discharge was terminated at the original 60-m site. The outfall presently extends approximately 7.2 km offshore to a depth of about 94 m, where the pipeline splits into a Y-shaped multiport diffuser system (i.e., wye). The two diffuser legs extend an additional 762 m to the north and south, each terminating at a depth of about 98 m.

The average daily flow of effluent through the Point Loma outfall in 2010 was 157 mgd, ranging from a low of 140 mgd in July to a high of about 394 mgd in December. Overall, this represents about a 2.6% increase from the average flow rate of 153 mgd in 2009. TSS removal averaged about 88% in 2010, with a total mass emissions of approximately 8006 mt/yr compared to 6774 mt/yr in 2009 (see City of San Diego 2011a).

Receiving Waters Monitoring

Prior to 1994, the City conducted an extensive ocean monitoring program off Point Loma surrounding the original 60-m discharge site. This program was subsequently modified and expanded with the construction and operation of the deeper outfall.

Data from the last year of regular monitoring near the original inshore site are presented in City of San Diego (1995a), while the results of a 3-year “recovery study” are summarized in City of San Diego (1998). From 1991 through 1993, the City also conducted a “pre-discharge” study in the vicinity of the new site in order to collect baseline data prior to the discharge of effluent in these deeper waters (City of San Diego 1995a, b). Results of NPDES mandated monitoring for the extended PLOO from 1994 to 2009 are available in previous annual receiving waters monitoring reports (e.g., City of San Diego 2010). In addition, the City has conducted annual region wide surveys off the coast of San Diego since 1994 either as part of regular South Bay outfall monitoring requirements (e.g., City of San Diego 1999, 2011b) or as part of larger, multi-agency surveys of the entire Southern California Bight (SCB). The latter include the 1994 Southern California Bight Pilot Project (Allen et al. 1998, Bergen et al. 1998, 2001, Schiff and Gossett 1998) and subsequent Bight’98 and Bight’03 programs in 1998 and 2003, respectively (Allen et al. 2002, 2007, Noblet et al. 2003, Ranasinghe et al. 2003, 2007, Schiff et al. 2006), as well as the current Bight’08 regional monitoring survey that began during the summer of 2008 (Bight’08 Coastal Ecology Committee 2008). Such large-scale surveys are useful for characterizing the ecological health of diverse coastal areas and may help to identify and distinguish reference sites from those impacted by wastewater or stormwater discharges, urban runoff, or other sources of contamination.

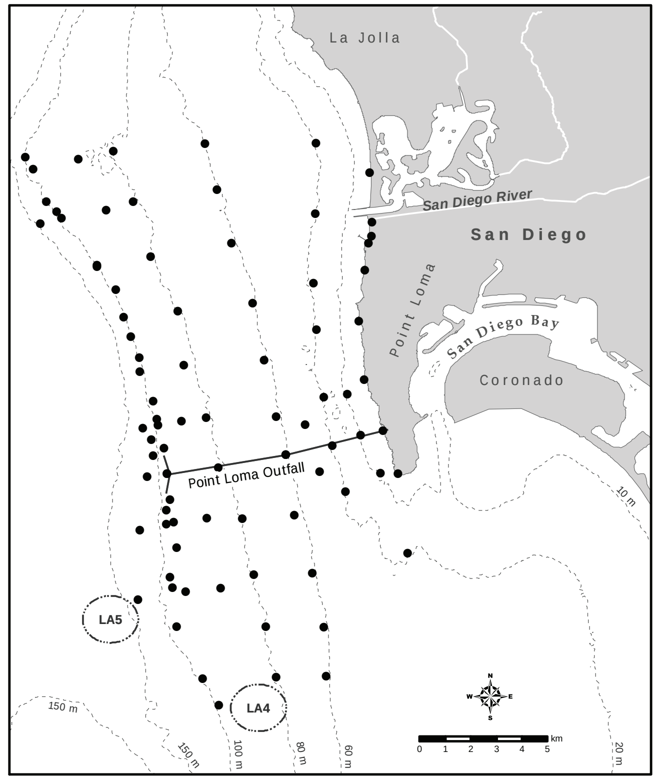


Figure 1.1
Receiving waters monitoring stations for the Point Loma Ocean Outfall Monitoring Program.

The current sampling area off Point Loma extends from the shoreline seaward to a depth of about 116 m and encompasses an area of approximately 184 km^2 (Figure 1.1). Fixed sites are generally arranged in a grid surrounding the outfall and are monitored in accordance with a prescribed sampling schedule. Results of relevant quality assurance procedures for the receiving waters monitoring activities are included in the City’s Environmental Monitoring and Technical Services (EMTS) Division Laboratory Quality Assurance Report (City of San Diego 2011c). Data files, detailed methodologies, completed reports, and other pertinent information submitted to the RWQCB and United States Environmental Protection Agency (USEPA) throughout the year are available online at the City’s website (www.sandiego.gov/mwwd/environment/oceanmonitor.shtml).

In addition to the above activities, the City participates in or supports other projects relevant to assessing ocean quality in the region. One such project involves satellite and aerial monitoring of the San Diego/Tijuana coastal region that is jointly funded by the City and the International Boundary and Water Commission (USIBWC) (Svejkovsky 2011). A long-term study of the Point Loma kelp forest funded by the City is also being conducted by scientists at the Scripps Institution of Oceanography (SIO), while the City also participates with a number of other agencies to fund aerial surveys of all the major kelp beds from San Diego and Orange Counties (MBC Applied Environmental Sciences 2010). Finally, the current MRP includes plans to perform adaptive or special strategic process studies as determined by the City in conjunction with the RWQCB and USEPA. Such studies have included a comprehensive scientific review of the Point Loma ocean monitoring program (SIO 2004), a large-scale sediment mapping study of the Point Loma and South Bay coastal regions (Stebbins et al. 2004), and an ongoing study of deep benthic habitats of the continental slope off San Diego (Stebbins and Parnell 2005). Additional work in these deeper habitats is ongoing with a final report expected in late 2011. In 2004 the City also began sampling at the recovery stations mentioned above as part of a long-term annual assessment project of benthic conditions near the original outfall discharge site. In addition, a multi-phase project is currently underway to examine the dynamics and strength of the thermocline and local currents of the receiving waters off Point Loma as well as the dispersion behavior of the PLOO wastewater plume (Storms et al. 2006, Dayton et al. 2009, Parnell and Rasmussen 2010).

This report presents the results of all regular receiving waters monitoring activities conducted as part of the Point Loma ocean monitoring program in 2010. The major components of the monitoring program are covered in the following chapters: Oceanographic Conditions, Water Quality, Sediment Conditions, Macrobenthic Communities, Demersal Fishes and Megabenthic Invertebrates, and Bioaccumulation of Contaminants in Fish Tissues. A glossary of technical terms is included.

Literature Cited

Allen, M.J., S.L. Moore, K.C. Schiff, S.B. Weisberg, D. Diener, J.K. Stull, A. Groce, J. Mubarak, C.L. Tang, and R. Gartman. (1998). Southern California Bight 1994 Pilot Project: V. Demersal Fishes and Megabenthic Invertebrates. Southern California Coastal Water Research Project, Westminster, CA.

Allen, M.J., A.K. Groce, D. Diener, J. Brown, S.A. Steinert, G. Deets, J.A. Noblet, S.L. Moore, D. Diehl, E.T. Jarvis, V. Raco-Rands, C. Thomas, Y. Ralph, R. Gartman, D. Cadien, S.B. Weisberg, and T. Mikel. (2002). Southern California Bight 1998 Regional Monitoring Program: V. Demersal Fishes and Megabenthic Invertebrates. Southern California Coastal Water Research Project. Westminster, CA.

Allen, M.J., T. Mikel, D. Cadien, J.E. Kalman, E.T. Jarvis, K.C. Schiff, D.W. Diehl, S.L. Moore, S. Walther, G. Deets, C. Cash, S. Watts, D.J. Pondella II, V. Raco-Rands, C. Thomas, R. Gartman, L. Sabin, W. Power, A.K. Groce, and J.L. Armstrong. (2007). Southern California Bight 2003 Regional Monitoring Program: IV. Demersal Fishes and Megabenthic Invertebrates. Southern California Coastal Water Research Project. Costa Mesa, CA.

Bergen, M., S.B. Weisberg, D. Cadien, A. Dalkey, D. Montagne, R.W. Smith, J.K. Stull, and R.G. Velarde. (1998). Southern California Bight 1994 Pilot Project: IV. Benthic Infauna. Southern California Coastal Water Research Project, Westminster, CA.

Bergen, M., S.B. Weisberg, R.W. Smith, D.B. Cadien, A. Dalkey, D.E. Montagne, J.K. Stull, R.G. Velarde, and J.A. Ranasinghe. (2001). Relationship between depth, sediment, latitude, and the structure of benthic infaunal assemblages on the mainland shelf of southern California. Marine Biology, 138: 637–647.

Bight'08 Coastal Ecology Committee. (2008). Southern California Bight Regional Marine Monitoring Survey (Bight'08) Coastal Ecology Workplan. Southern California Coastal Water Research Project, Costa Mesa, CA. [available at www.sccwrp.org]

City of San Diego. (1995a). Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 1994. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (1995b). Outfall Extension Pre-Construction Monitoring Report (July 1991–October 1992). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (1998). Recovery Stations Monitoring Report for the Original Point Loma Ocean Outfall (1991–1996). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (1999). San Diego Regional Monitoring Report for 1994–1997. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2009. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2011a). 2010 Annual Reports and Summary: Point Loma Wastewater Treatment Plant and Point Loma Ocean Outfall. City of San Diego, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2011b). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2010. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2011c). EMTS Division Laboratory Quality Assurance Report, 2010. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Dayton, P., P.E. Parnell, L.L. Rasmussen, E.J. Terrill, and T.D. Stebbins. (2009). Point Loma Ocean Outfall Plume Behavior Study, Scope of Work. Scripps Institution of Oceanography, La Jolla, CA, and City of San Diego, Metropolitan Wastewater Department, San Diego, CA. [NOAA Award No. NA08NOS4730441]

MBC Applied Environmental Sciences. (2010). Status of the Kelp Beds 2009, San Diego and Orange Counties, Region Nine Kelp Survey Consortium. Final Report, June 2010. MBC Applied Environmental Sciences, Costa Mesa, CA.

Noblet, J.A., E.Y. Zeng, R. Baird, R.W. Gossett, R.J. Ozretich, and C.R. Phillips. (2003). Southern California Bight 1998 Regional Monitoring Program: VI. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

Parnell, E. and L. Rasmussen. (2010). Summary of PLOO hydrographic observations (2006–2009). Draft report to City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Ranasinghe, J.A., D.E. Montagne, R.W. Smith, T.K. Mikel, S.B. Weisberg, D. Cadien, R. Velarde, and A. Dalkey. (2003). Southern California Bight 1998 Regional Monitoring Program: VII. Benthic Macrofauna. Southern California Coastal Water Research Project. Westminster, CA.

Ranasinghe, J.A., A.M. Barnett, K. Schiff, D.E. Montagne, C. Brantley, C. Beegan, D.B. Cadien, C. Cash, G.B. Deets, D.R. Diener, T.K. Mikel, R.W. Smith, R.G. Velarde, S.D. Watts, and S.B. Weisberg. (2007). Southern California Bight 2003 Regional Monitoring Program: III. Benthic Macrofauna. Southern

California Coastal Water Research Project. Costa Mesa, CA.

Schiff, K.C. and R.W. Gossett. (1998). Southern California Bight 1994 Pilot Project: III. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

Schiff, K., K. Maruya, and K. Christenson. (2006). Southern California Bight 2003 Regional Monitoring Program: II. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

Scripps Institution of Oceanography. (2004). Point Loma Outfall Project, Final Report, September 2004. Scripps Institution of Oceanography, University of California, La Jolla, CA.

Stebbins, T.D. and P.E. Parnell. (2005). San Diego Deep Benthic Pilot Study: Workplan for Pilot Study of Deep Water Benthic Conditions off Point Loma, San Diego, California. City of San Diego, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, and Scripps Institution of Oceanography, La Jolla, CA.

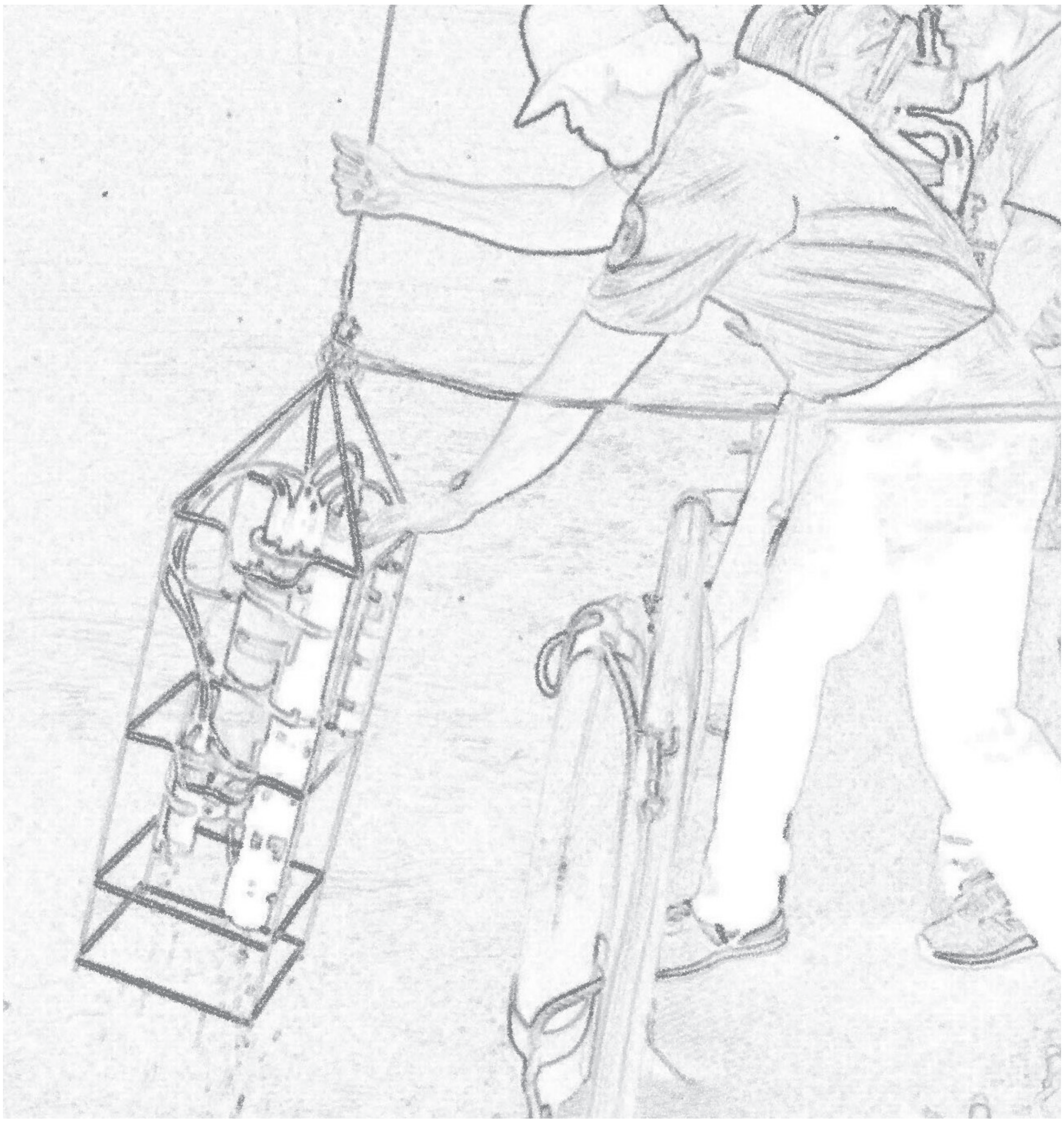
Stebbins, T.D., K.C. Schiff, and K. Ritter. (2004). San Diego Sediment Mapping Study: Workplan for Generating Scientifically Defensible Maps of Sediment Conditions in the San Diego Region. City of San Diego, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, and Southern California Coastal Water Research Project, Westminster, CA.

Storms, W.E., T.D. Stebbins, and P.E. Parnell. (2006). San Diego Moored Observation System Pilot Study Workplan for Pilot Study of Thermocline and Current Structure off Point Loma, San Diego, California. City of San Diego, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, and Scripps Institution of Oceanography, La Jolla, CA.

Svejkovsky, J. (2011). Satellite and Aerial Coastal Water Quality Monitoring in the San Diego/ Tijuana Region. Annual Summary Report, 1 January, 2010 – 31 December 2010. Ocean Imaging, Solana Beach, CA.

This page intentionally left blank

Chapter 2
Oceanographic Conditions



Chapter 2. Oceanographic Conditions

Introduction

The City of San Diego monitors oceanographic conditions in the region surrounding the Point Loma Ocean Outfall (PLOO) to assist in evaluating possible impacts of wastewater discharge on the local marine environment. Measurements of water temperature, salinity, density, light transmittance (transmissivity), dissolved oxygen, pH, and chlorophyll concentrations are important indicators of biological and physical oceanographic processes (Skirrow 1975) that can impact marine life within a region (Mann 1982, Mann and Lazier 1991). In addition, because the fate of wastewater discharged into marine waters is determined not only by the geometry of an ocean outfall's diffuser structure and the rate of discharge, but also by oceanographic factors that affect water mass movement (e.g., horizontal and vertical mixing of the water column, current patterns), evaluations of physical parameters that influence the mixing potential of the water column are important components of ocean monitoring programs (Bowden 1975, Pickard and Emery 1990). For example, the degree of vertical mixing or stratification, and the depth at which the water column is stratified, indicates the likelihood and depth of wastewater plume trapping.

In coastal waters such as the Point Loma monitoring region, oceanographic conditions are strongly influenced by seasonal changes (Bowden 1975, Skirrow 1975, Pickard and Emery 1990). In southern California for example, differences between the typical wet, winter months (e.g., December–February) and dry, summer months (e.g., July–September) can affect water column mixing (horizontal and vertical), degree and depth of stratification, and current patterns. Consequently, events such as strong winter storms often bring higher winds, rain and waves, which in turn contribute to the formation of a well-mixed, and relatively homogenous (non-stratified) water column (Jackson 1986). Additionally, changes in ocean currents and the movement of water masses in and out of a study area can affect mixing conditions. The chance that wastewater plumes from sources such as the PLOO may surface is highest when the water column is well mixed and there is little, if any, stratification. In contrast, the likelihood of the plume surfacing decreases as the water column becomes more stratified such as during late spring through early fall.

Understanding changes in oceanographic conditions due to natural processes like seasonal patterns and shifting current regimes is important since they can affect the transport and distribution of wastewater, storm water and other types of sediment or contaminant plumes. In the Point Loma region such processes include tidal exchange from local bays, outflows from major rivers, lagoons and estuaries, discharges from storm drains or other point sources, surface water runoff from local watersheds, seasonal upwelling and changing ocean currents or eddies. For example, flows from San Diego Bay and the Tijuana River are fed by 1075 km^2 and 4483 km^2 of watershed, respectively, and can contribute significantly to turbidity plumes in nearshore waters, sediment deposition, and bacterial contamination (Largier et al. 2004, Terrill et al. 2009). Overall, these different sources can affect water quality conditions both individually and synergistically.

This chapter describes the main oceanographic conditions present in the Point Loma region during 2010 and compares these patterns to historical data. The results of remote sensing observations (e.g., aerial and satellite imagery) may also provide useful information on the horizontal transport of surface waters (Pickard and Emery 1990, Svejkovsky 2011). Thus, this chapter combines measurements of physical oceanographic parameters with assessments of remote sensing data to provide further insight into the transport potential in coastal waters surrounding the PLOO discharge site.

In addition to the above, a multi-phase project is currently underway to examine the dynamics and strength of the thermocline and ocean currents off Point Loma, as well as the dispersion behavior of the PLOO wastewater plume using a combination of current meters (ADCPs), thermistor strings, and automated underwater vehicles (AUVs) (see Storms et al. 2006, Dayton et al. 2009, Parnell and Rasmussen 2010). Some initial results from this project are incorporated herein (e.g., ADCP current measurements and thermistor data from 2010), while others will be included in future reports as they become available. Finally, the oceanographic results reported in this chapter are also referred to in Chapters 3–7 to help explain patterns in the distribution of indicator bacteria in the coastal waters off Point Loma, as well as other changes in the local marine environment.

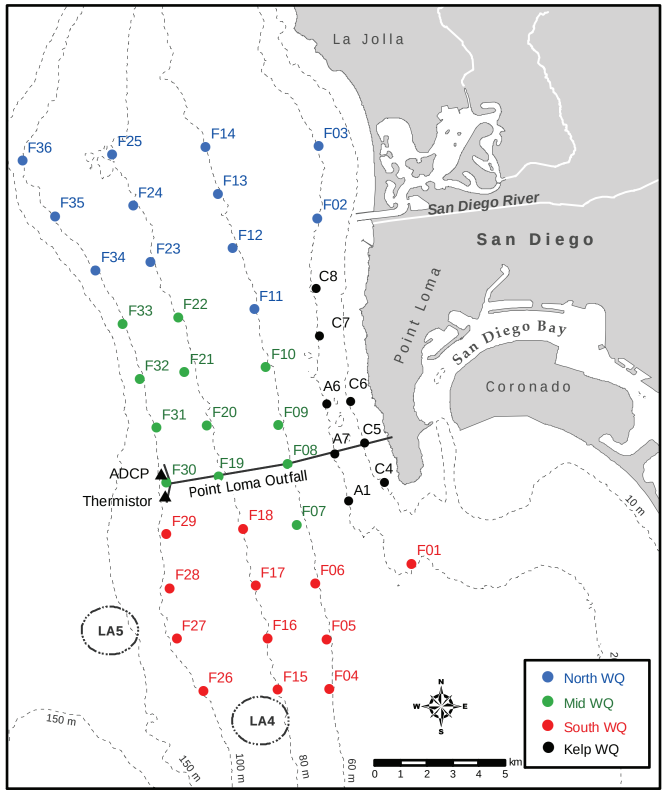


Figure 2.1
Locations of moored instruments (i.e., ADCP, thermistor) and water quality monitoring stations where CTD casts are taken, Point Loma Ocean Outfall Monitoring Program.

Materials and Methods

Field Sampling

Oceanographic measurements were taken at a total of 44 stations encompassing an area of ~146 km^2 surrounding the PLOO (Figure 2.1). This includes 36 offshore stations (F01–F36) located between ~1.7–10.2 km offshore of Point Loma along or adjacent to the 18, 60, 80 and 98-m depth contours, and eight kelp bed stations (A1, A6, A7, C4–C8) distributed along the inner (9 m) and outer (18 m) edges of the Point Loma kelp forest as described in Chapter 3. Monitoring at the offshore stations occurs quarterly, typically during the months of February, May, August and November in order to correspond to similar sampling for the Central Bight Regional Water Quality Monitoring Program conducted off Orange County, Los Angeles County, and Ventura County. However, sampling during the first quarter of 2010 was postponed until March to accommodate another Bight'08 related water quality project.

For sampling and analysis purposes, the above quarterly water quality monitoring sites are organized into northern (North WQ), mid-region (Mid-WQ), and southern (South WQ) groups, with each group composed of 12 stations: (a) North WQ = stations F02, F03, F11–F14, F23–F25, and F34–F36; (b) Mid-WQ = stations F07–F10, F19–F22, and F30–F33; (c) South WQ = stations F01, F04–F06, F15–F18, and F26–F29. All stations within each of these three groups are sampled on a single day during each quarterly survey. In addition, sampling at the eight kelp bed (Kelp WQ) stations is conducted five times per month to meet monitoring requirements for fecal indicator bacteria (see Chapter 3); however, only Kelp WQ data collected within about 1–2 days of the above quarterly stations are analyzed in this chapter.

In order to minimize differences between oceanographic parameters reflecting large-scale changes in water masses, the above four station groups are sampled as close together as possible, which typically occurs over 4–5 days. However, due to poor weather conditions, the March 2010 survey spanned a 12-day period, with one week occurring between the Mid-WQ station group survey and those of the other three groups (see

Table 2.1). Consequently, data for the March survey should be interpreted with caution as differences in oceanographic parameters may be due to temporal changes in water masses rather than spatial differences between sites.

Data for the various oceanographic parameters were collected using a SeaBird CTD (conductivity, temperature, and depth) instrument. The CTD was lowered through the water column at each station at a continuous rate to collect measurements of water temperature, salinity, density, pH, transmissivity (a proxy for water clarity), chlorophyll *a* (a proxy for the presence of phytoplankton), and dissolved oxygen (DO). Profiles of each parameter were then constructed for each station by averaging the data values recorded over 1-m depth intervals. This data averaging ensured that physical measurements used in subsequent analyses would correspond to discrete sampling depths for fecal indicator bacteria (see Chapter 3). Visual observations of weather and water conditions were recorded just prior to each CTD cast.

Moored Instruments

Moored instruments, including current meters (ADCPs: Acoustic Doppler Current Profilers) and vertical arrays of temperature sensors (thermistors) were deployed at two primary locations off Point Loma in order to provide continuous measurements of ocean currents and water temperatures for the area. These included one site near the present PLOO discharge site at a depth of about 100 m, and one site located south of the outfall along the 60-m depth contour.

Ocean current data were collected using one ADCP moored at each of the above sites throughout 2010. The ADCP data were collected every five minutes and then averaged into 25 depth bins of 4 m each. The depth bins used for this analysis ranged from 5 to 93 m. Additional details for processing and analyzing the ADCP data are presented below under "Data Treatment and Analysis". Only data from the 100-m contour were used in the initial analysis included herein.

Temperature data were collected every 10 minutes throughout 2010 from thermistor strings located at the 100-m and 60-m mooring sites. The individual thermistors (Onset Tidbit temperature loggers) were deployed on mooring lines at each site starting at 2 m off the seafloor and extending in series every 4 m to within 6 m of the surface. Occasional gaps exist in the time series where individual thermistors were lost at sea or failed to record data properly. As with the ADCP data, only thermistor data from the 100-m contour site were analyzed for this report. Further details on specific methodology are available in Storms et al. (2006).

Remote Sensing – Aerial and Satellite Imagery

Coastal monitoring of the PLOO region during 2010 included remote imaging analyses performed by Ocean Imaging (OI) of Solana Beach, CA. All satellite and aerial imaging data collected during the year are made available for review and download from OI's website (Ocean Imaging 2011), while a separate annual report to summarize these data is also produced (Svejkovsky 2011). This chapter includes examples of Rapid Eye satellite imagery. Examples of multispectral color imagery from OI's DMSC-MKII aerial sensor and thermal infrared (IR) imagery from a Jenoptik thermal imager integrated into the system are also included. These technologies differ in terms of their resolution, frequency of collection, depth of penetration, and detection capabilities as described in the "Technology Overview" section of Svejkovsky (2011).

Data Treatment and Analysis

Data for the various oceanographic parameters measured off Point Loma in 2010 were analyzed in several different ways, including: (a) calculation of basic descriptive metrics by depth; (b) spatial analysis using Interactive Geographical Ocean Data System (IGODS) software; (c) comparison of long-term anomalies for each parameter since pre-discharge monitoring began in 1991. Each of the water column parameters measured in 2010 were summarized as monthly means of both surface waters (top 2 m) and bottom waters (bottom 2 m)

Table 2.1
Sample dates for quarterly oceanographic surveys conducted off Point Loma during 2010. Each survey was conducted over four days, with all stations in each station group sampled on a single day (see text and Figure 2.1 for list of stations and station locations). Survey Span = number of days between first and last day of sampling for each survey.

	2010 Quarterly Survey Dates			
Station Group	**March**	**May**	**August**	**November**
North WQ	2 Mar 10	5 May 10	9 Aug 10	2 Nov 10
Mid-WQ	12 Mar 10	6 May 10	12 Aug 10	3 Nov 10
South WQ	1 Mar 10	4 May 10	11 Aug 10	4 Nov 10
Kelp WQ	5 Mar 10	7 May 10	13 Aug 10	6 Nov 10
Survey Span	*12 days*	*4 days*	*5 days*	*5 days*

over all stations located along the 9, 18, 60, 80, and 98-m depth contours to provide an overview of trends across depth throughout the region. For spatial analysis, 3-dimensional graphical views were created using IGODS software, which uses a linear interpolation between stations and with depth at each site. Additional analysis included vertical profiles using the 1-m binned data for each parameter plotted using IGODS, but limited to a subset of seven of the 98-m stations (i.e., F27–F33). These profiles were created to provide a more detailed view of data depicted in the IGODS graphics. Finally, a time series of "anomalies" for each parameter was created to evaluate significant oceanographic events off Point Loma between 1991 and 2010. These anomalies were calculated by subtracting the monthly means for each year from the mean of all 20 years combined. These values were calculated using data from all stations located along the 98-m depth contour with all depths combined.

Because ocean currents often vary by season, the ADCP-derived current data were divided into four seasons prior to conducting subsequent analyses, including: (a) winter (December, January, February); (b) spring (March, April, May); (c) summer (June, July, August); (d) fall (September, October, November). Although the winter period includes non-continuous months (i.e., January–February vs. December), preliminary analysis suggested that the current regimes for these three months were similar enough to justify pooling them together for this year's analysis. Since tidal currents are predictable and not likely to result in a net flow of water in a particular direction, tides were filtered prior to any data visualization or analysis using the PL33 filter developed by C. Flagg and R. Beardsley (Alessi et al. 1984). In order to visualize raw current data with tides removed on a seasonal basis (tide-removed data), current data were averaged by hour and plotted for four representative depth bins on compass plots; these mid-bin depths were 11 m, 35 m, 63 m and 91 m. In order to examine modes of currents that were present each season, an empirical orthogonal function (EOF) analysis was completed by singular value decomposition in MATLAB. Each current mode was plotted on compass plots for the same depth bins as tide-removed data. Although dominant physical processes are likely to be present in the first few EOFs, there is not always exact correspondence between EOFs and physical modes. Consequently, visualization of tide-removed data was used to assist in EOF interpretation. In all seasons, the first two EOFs described >97% of the total variability.

Results

Oceanographic Conditions in 2010

Water temperature and density

Seawater density is determined by temperature, salinity and pressure. In the shallower coastal waters of southern California and elsewhere, density is

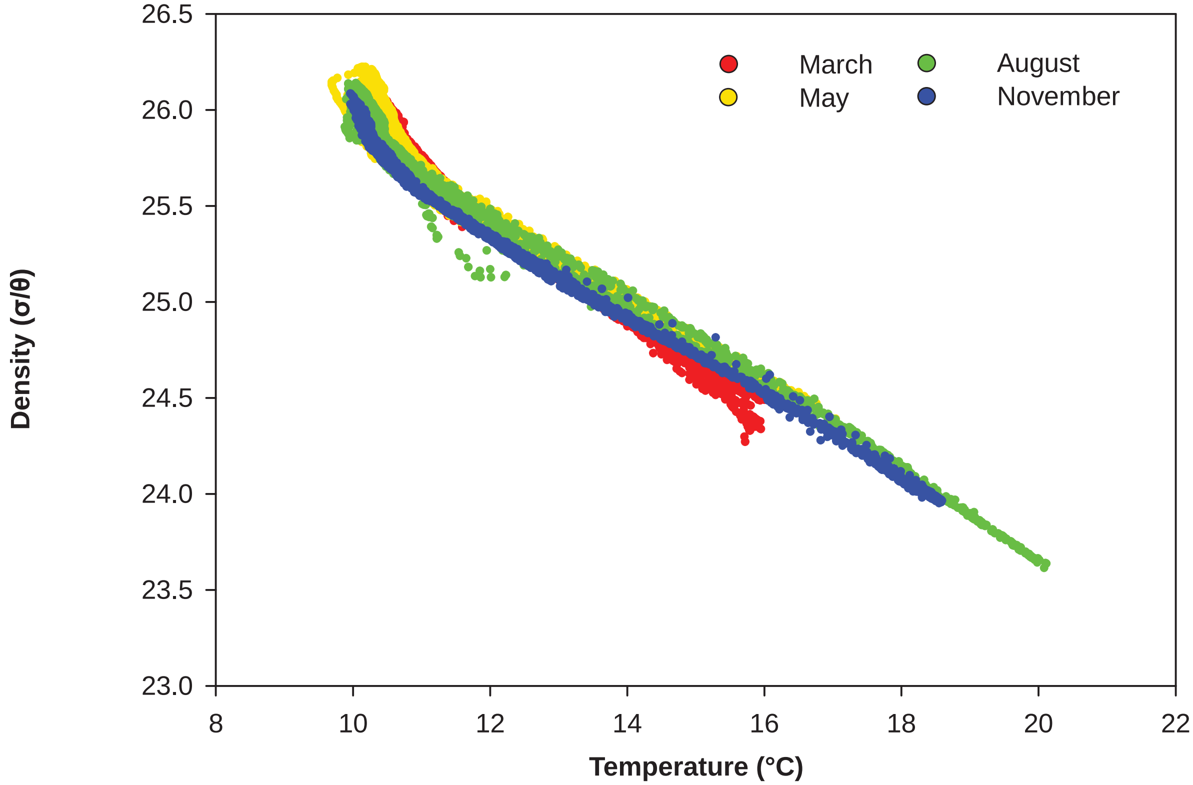


Figure 2.2
Scatterplot of temperature and density for PLOO stations sampled in 2010. Pearson correlation coefficient $r(11,619) = 0.98$, $p < 0.001$.

influenced primarily by temperature differences since salinity is relatively uniform (Bowden 1975, Jackson 1986, Pickard and Emery 1990). Because of such a strong correlation between temperature and density off Point Loma in 2010 (Figure 2.2), the results discussed below for temperature can be assumed to also apply to density with the exception of the following slight deviations in March and August. Based on temperature data for example, seawater was less dense than expected in surface waters during March (Appendix A.1), which may be due to freshwater runoff associated with rainfall that occurred during the previous month. In addition, temperatures were lower than expected in August at mid- and bottom-depths of a few offshore stations, although the reason for this pattern is unknown.

Thermistor data from the 100-m mooring showed typical seasonal variations with a well-mixed water column during the winter (January–February, December) and a warmer surface layer with a shallower thermocline during the spring to fall months, punctuated by upwelling and cooling events (Figure 2.3). Using CTD data from all stations in 2010, mean surface temperatures across the entire Point Loma monitoring region ranged from 15.1°C in March to 19.7°C in August, while bottom temperatures ranged from 10.0°C in August to 16.0°C in November (Table 2.2). Although the offshore data are limited to only four surveys per year, ocean temperatures appeared to vary by season as expected, with no discernable patterns relative to wastewater discharge (Figures 2.4, 2.5). For example, the lowest temperatures of the year tended to occur during May and August at bottom depths, which probably reflect spring and summer upwelling in the region. Thermal stratification also followed expected seasonal patterns, with the greatest difference between surface and bottom waters (almost 10°C) occurring during the summer (i.e., August). Since temperature is the main contributor to water column stratification in southern California (Dailey et al. 1993, Largier et al. 2004), differences between surface and bottom

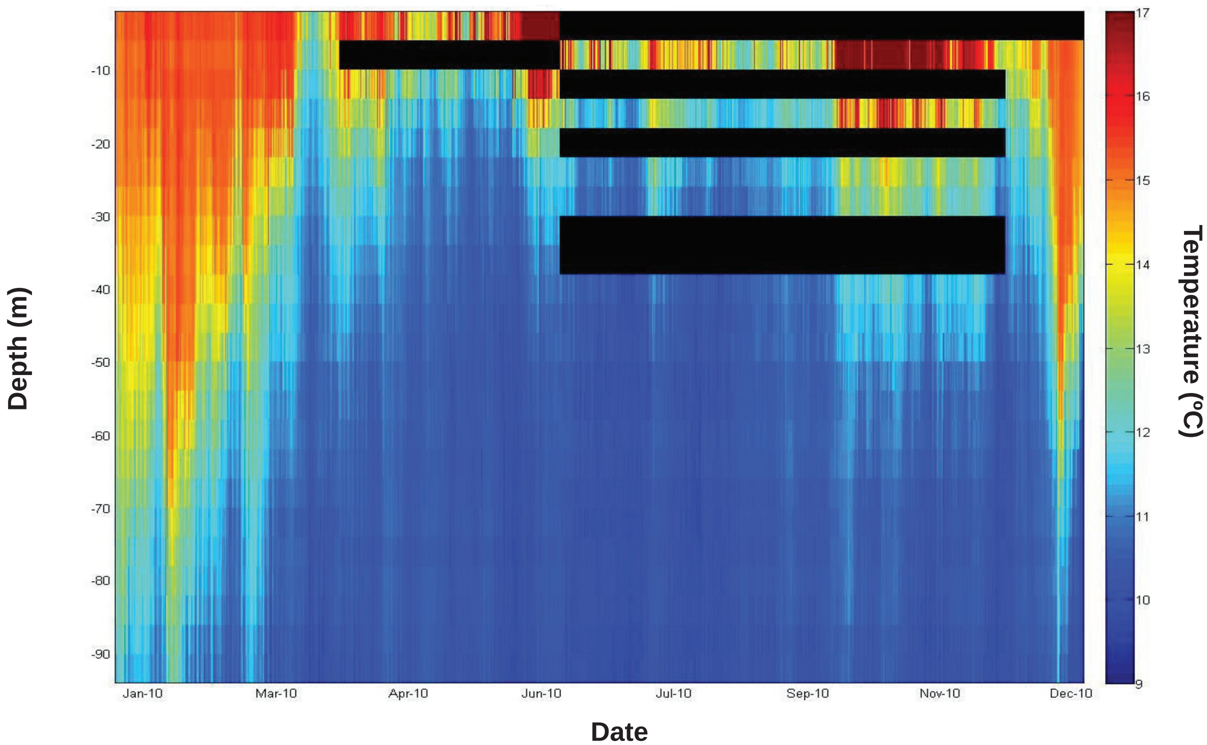


Figure 2.3
Temperature data collected at the 100-m thermistor site between January and December 2010. Data were collected every 10 minutes. Missing data are the result individual thermistors that were lost at sea or malfunctioning.

temperatures are important to limiting the surface potential of the wastefield throughout the year. Moreover, the wastewater plume from the PLOO was not visible in surface waters at any time during the year based on remote sensing observations (e.g., Figure 2.6; Svejkovsky 2011) or the results of discrete bacteriological samples (see Chapter 3).

In addition to region-wide phenomena such as upwelling seasonal changes in water column stratification, water temperatures varied among stations during each of the quarterly surveys conducted in 2010. For example, such differences were especially evident during the March survey, although this may have been because the four days of this survey were spread over 12 days instead of the usual 4–5 days due to poor weather (see Table 2.1). Consequently, differences between sampling sites in March were likely due to changes in oceanographic parameters associated with different water masses (Figures 2.4, 2.5).

Salinity

Average salinities for the region in 2010 ranged from a low of 33.2 psu in March to a high of 33.54 psu in May and August for surface waters, and from 33.29 psu in March to 34.07 psu in May at bottom depths (Table 2.2). As with ocean temperatures, salinity appeared to vary by season, with no discernable patterns relative to wastewater discharge (Figures 2.7, 2.8). The highest salinity values recorded during the year occurred at bottom depths during May and August and corresponded to the lower temperatures found in bottom waters as described above. Together these factors are indicative of coastal upwelling that is typical for spring and summer months (Jackson 1986). There was some evidence of another region-wide phenomenon that occurred during August and November (and in May to a lesser degree), when a layer of water with relatively low salinity values occurred at mid-water or “sub-surface” depths between about 10–40 m. It seems unlikely that this sub-surface salinity minimum (SSM) could be due to wastewater discharge from the PLOO for two reasons. First, seawater samples collected at the same depths and times did not contain elevated levels of indicator bacteria (see Chapter 3). Second, similar SSMs have been reported previously off San Diego and elsewhere

Table 2.2

Summary of temperature, salinity, dissolved oxygen, pH, transmissivity, and chlorophyll *a* for surface and bottom waters in the PLOO region during 2010. Values are expressed as means for each survey pooled over all stations along each depth contour.

		Mar	May	Aug	Nov			Mar	May	Aug	Nov
Temperature (^{o}C)						**pH**					
9-m	Surface	15.1	16.6	17.5	17.2	9-m	Surface	8.2	8.3	8.3	8.4
	Bottom	14.2	14.4	12.0	16.0		Bottom	8.1	8.1	7.9	8.3
18-m	Surface	15.6	15.8	17.5	17.5	18-m	Surface	8.2	8.3	8.3	8.3
	Bottom	13.3	11.5	11.3	13.0		Bottom	8.0	7.9	7.9	8.0
60-m	Surface	15.4	15.4	17.8	18.1	60-m	Surface	8.2	8.3	8.3	8.2
	Bottom	11.0	10.5	10.4	10.6		Bottom	7.8	7.7	7.8	7.8
80-m	Surface	15.5	15.7	18.9	18.3	80-m	Surface	8.2	8.3	8.3	8.2
	Bottom	10.8	10.3	10.2	10.3		Bottom	7.8	7.7	7.8	7.8
98-m	Surface	15.5	15.6	19.7	18.4	98-m	Surface	8.2	8.3	8.3	8.2
	Bottom	10.5	10.2	10.0	10.1		Bottom	7.8	7.7	7.8	7.7
Salinity (psu)						**Transmissivity (%)**					
9-m	Surface	33.22	33.54	33.54	33.42	9-m	Surface	61	72	79	77
	Bottom	33.29	33.53	33.47	33.40		Bottom	61	77	82	67
18-m	Surface	33.20	33.48	33.52	33.41	18-m	Surface	68	71	78	80
	Bottom	33.40	33.60	33.42	33.38		Bottom	67	82	79	78
60-m	Surface	33.22	33.47	33.53	33.43	60-m	Surface	78	78	79	88
	Bottom	33.68	33.94	33.77	33.54		Bottom	73	76	84	80
80-m	Surface	33.32	33.46	33.52	33.44	80-m	Surface	84	78	82	89
	Bottom	33.77	34.02	33.88	33.66		Bottom	78	85	86	84
98-m	Surface	33.35	33.43	33.53	33.46	98-m	Surface	87	83	84	89
	Bottom	33.84	34.07	33.93	33.77		Bottom	86	89	88	89
Dissolved Oxygen (mg/L)						**Chlorophyll *a* (µg/L)**					
9-m	Surface	7.8	9.7	8.9	8.3	9-m	Surface	4.0	12.5	7.4	3.9
	Bottom	7.0	7.2	5.4	6.8		Bottom	2.6	3.3	5.3	5.9
18-m	Surface	8.3	10.1	9.0	7.9	18-m	Surface	5.5	17.3	9.0	3.7
	Bottom	6.1	4.8	5.3	5.8		Bottom	2.7	7.6	17.1	3.5
60-m	Surface	8.2	10.0	9.2	8.1	60-m	Surface	2.8	9.3	6.9	2.0
	Bottom	4.2	2.6	3.4	4.8		Bottom	0.8	6.2	2.6	1.1
80-m	Surface	8.0	10.0	8.8	8.0	80-m	Surface	1.8	7.7	2.8	1.7
	Bottom	3.9	2.6	3.1	4.2		Bottom	0.4	3.0	1.0	0.6
98-m	Surface	8.0	9.3	8.3	7.8	98-m	Surface	1.6	4.2	2.0	1.6
	Bottom	3.8	2.4	3.0	3.9		Bottom	0.4	0.6	0.8	0.5

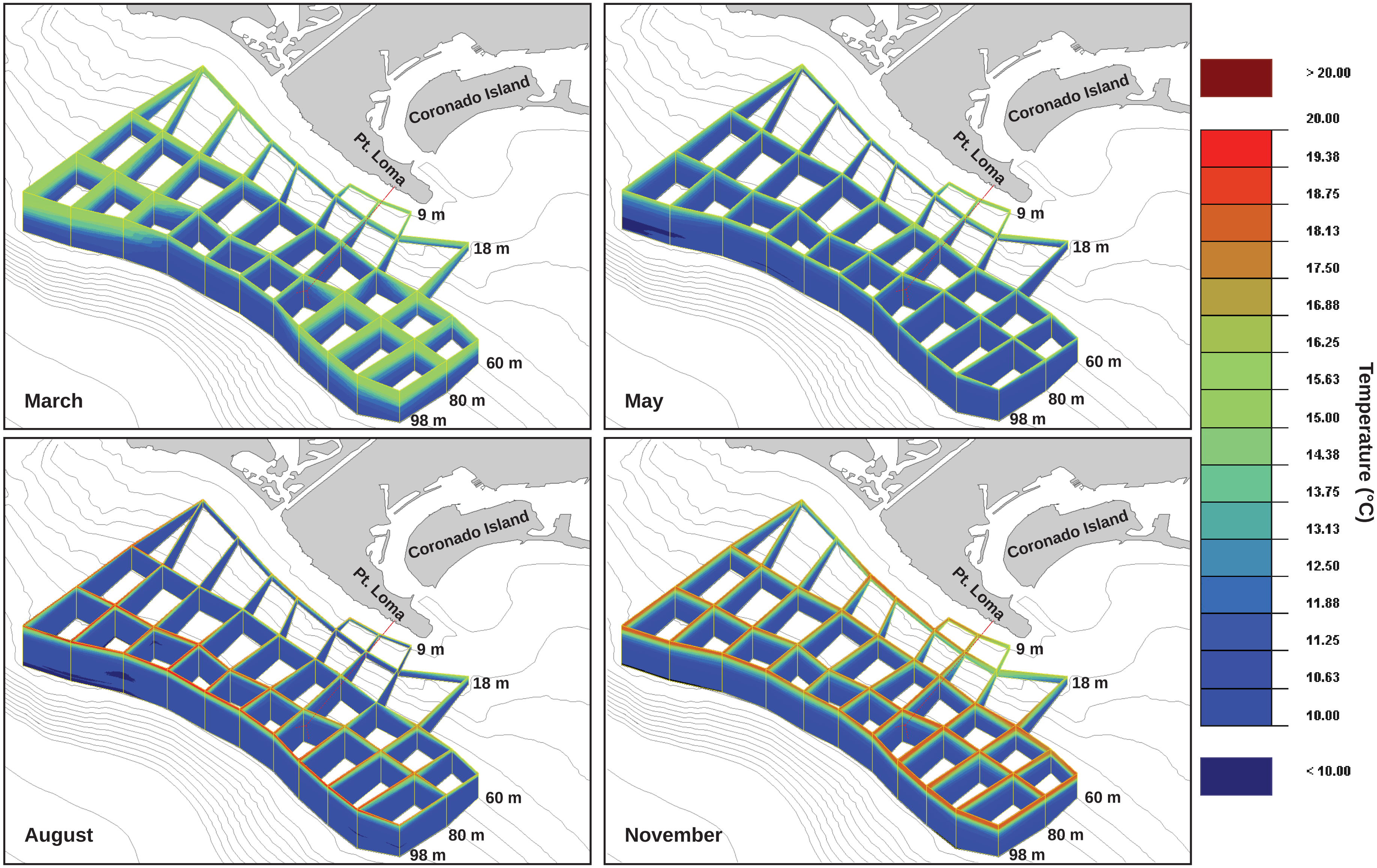


Figure 2.4
Ocean temperatures recorded in 2010 for the PLOO region. Data are collected over four days during each of these quarterly surveys; see Table 2.1 and text for specific sample dates and stations sampled each day.

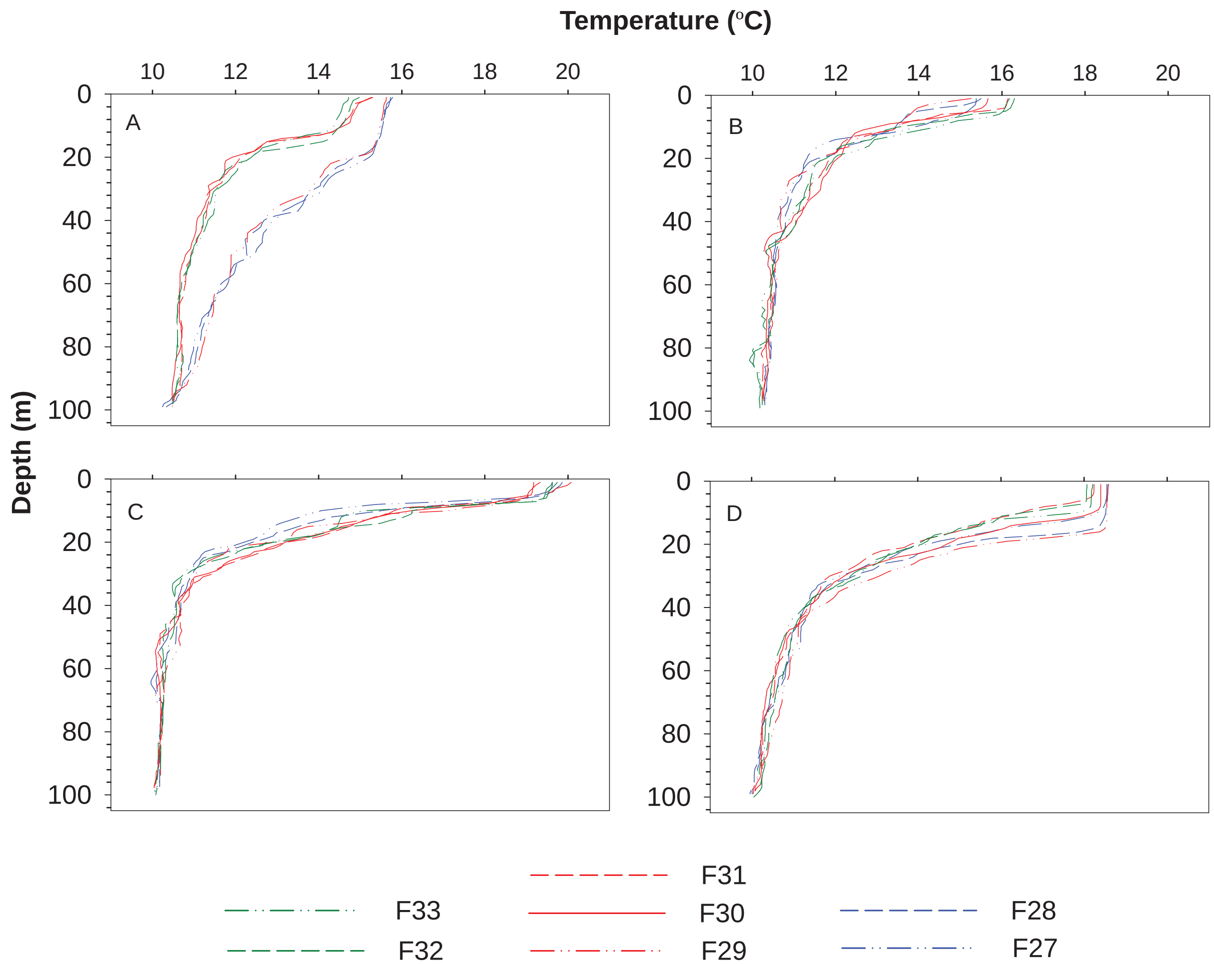


Figure 2.5
Vertical profiles of ocean temperature for PLOO stations F27–F33 during each 2010 quarterly survey.

in southern California, including: (a) the Point Loma monitoring region during the summer and fall of 2009 (City of San Diego 2010a); (b) the South Bay outfall monitoring region during 2009 and 2010 (City of San Diego 2010b, 2011); (c) coastal waters off Orange County, California for many years (e.g., OCSD 1999); (d) coastal waters extending as far north as Ventura, California (OCSD 2009). Further investigations are required to determine the possible source(s) of this phenomenon.

Dissolved oxygen and pH

Dissolved oxygen (DO) concentrations averaged from 7.8 to 10.1 mg/L in surface waters and from 2.4 to 7.2 mg/L in bottom waters across the Point Loma region in 2010, while mean pH values ranged from 8.2 to 8.4 in surface waters and from 7.7 to 8.3 in bottom waters (Table 2.2). Changes in pH were closely linked to changes in DO since both parameters tend to reflect the loss or gain of carbon dioxide associated with biological activity in shallow waters (Skirrow 1975).

Stratification of the water column followed typical seasonal cycles for DO, with maximum differences between surface and bottom waters occurring in May (Table 2.2, Appendices A.2, A.3). Low DO concentrations at mid- and deeper depths during the spring and summer were likely related to cold, saline and oxygen poor waters moving inshore during periods of coastal upwelling as discussed previously for temperature and salinity. In contrast, very high DO values just below surface waters (i.e., at the thermocline) were likely associated with phytoplankton blooms as evident by high chlorophyll values at the same depths and surveys.

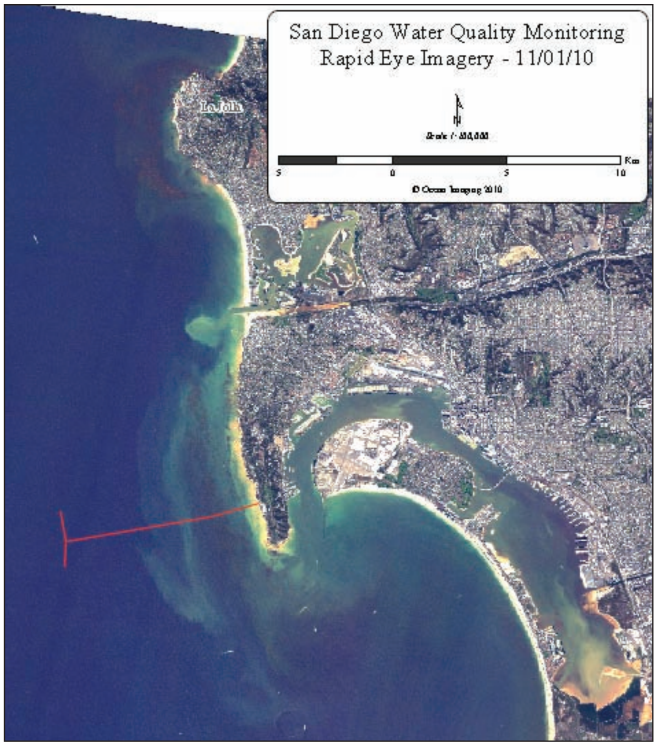


Figure 2.6
Rapid Eye satellite image of the Point Loma region acquired November 1, 2010 (Ocean Imaging 2011) showing typical clear water conditions over the PLOO with no visible evidence of the wastewater plume reaching surface waters.

Transmissivity
Water clarity appeared to vary within typical ranges for the PLOO region during 2010, with average transmissivity values between 61–89% in surface and bottom waters (Table 2.2). Transmissivity was consistently higher at the offshore sites than in inshore waters, by as much as 26% at the surface and 25% near the bottom. Reduced transmissivity at surface and mid-water depths tended to co-occur with peaks in chlorophyll concentrations associated with phytoplankton blooms (see Ocean Imaging 2011, Svejkovsky 2011, and Appendices A.4, A.5, A.6, A.7). Lower transmissivity during March and November at the stations located in inshore waters along the 9 and 18-m depth contours may also have been due to wave and storm activity and resultant increases in suspended sediment concentrations. In contrast, reductions in transmissivity that occurred offshore at depths >60 m were more likely associated with wastewater discharge from the PLOO. For example, reductions in water clarity at the three stations nearest the discharge site were most evident in March and May (Appendix A.5).

***Chlorophyll* a**
Mean chlorophyll concentrations across the PLOO region ranged from 0.4 μg/L near the bottom in March to 17.3 μg/L at the surface in May (Table 2.2). However, further analysis clearly showed that the highest chlorophyll values tended to occur at sub-surface depths (Appendices A.6, A.7). Although these results may reflect the presence of phytoplankton massing near the bottom of the thermocline where nutrient levels are high and light is not yet limiting, additional work is necessary to determine the thermocline boundaries off Point Loma in order to confirm this hypothesis. The highest concentrations of chlorophyll in 2010 were observed 10–20 m below the surface during May and August across much of the region, which corresponds to coastal upwelling indicated by the low water temperatures, high salinity, and low DO values at bottom depths as described previously. Additionally, high chlorophyll values in May corresponded to a phytoplankton bloom observed by remote sensing that extended across the entire region by the end of the month (Figure 2.9; also see Svejkovsky 2011). This relationship between coastal upwelling and plankton blooms has been well documented by remote sensing observations over the years (City of San Diego 2010b, 2011, Svejkovsky 2011).

Summary of Ocean Currents in 2010

Winter 2010
Tide-removed data plotted for winter 2010 show the highest magnitude ocean currents observed during 2010 (Figure 2.10A). The predominant current directions during January, February and December were north and south, but slightly skewed northwest and southeast in the 11, 35, and 91-m depth bins. The 91-m depth bin had its strongest currents in the north and south directions, but also had the lowest magnitude currents of all depth bins.

The first EOF explains 91.5% of the variability (Figure 2.11A). This EOF shows predominant

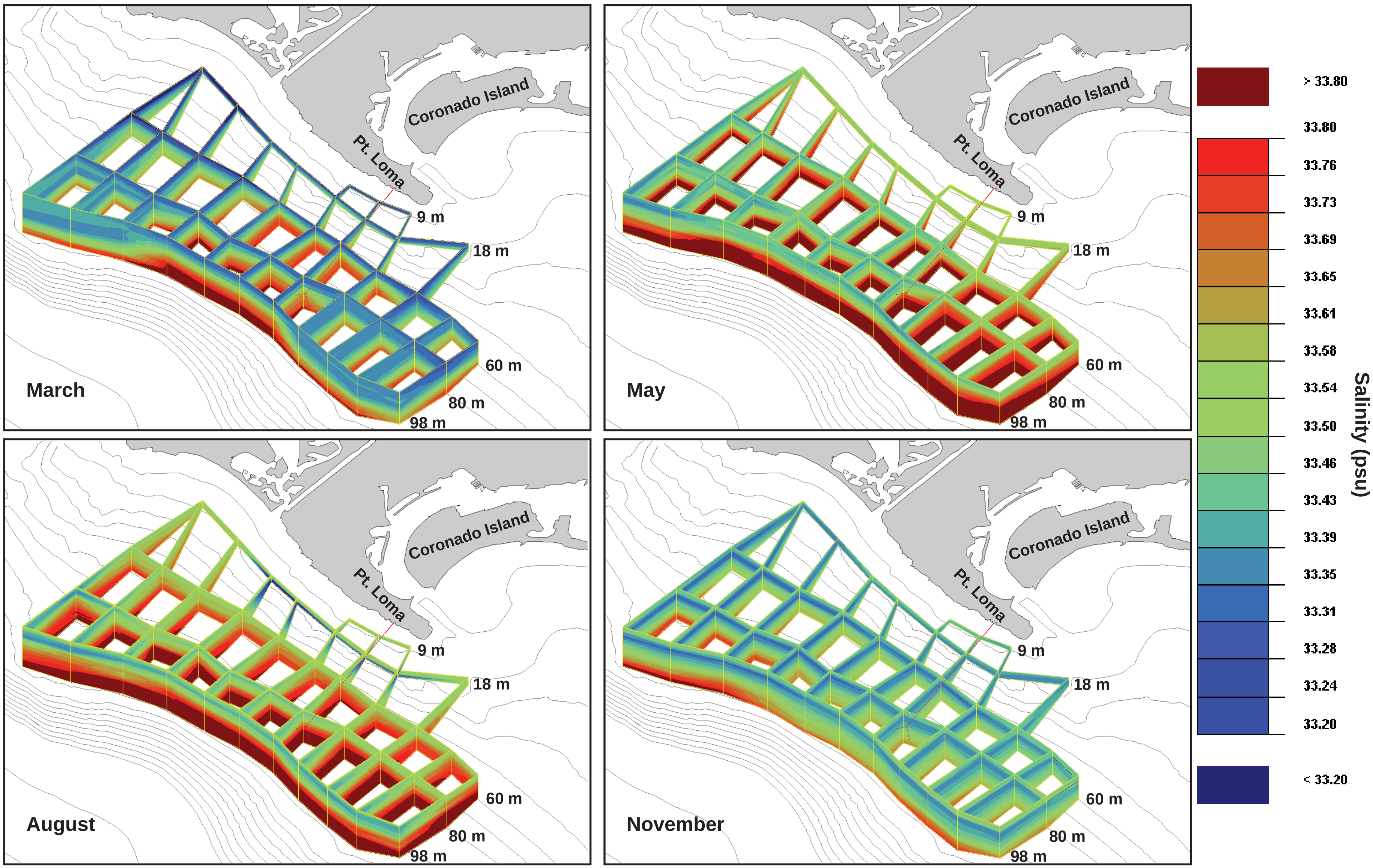


Figure 2.7
Levels of salinity recorded in 2010 for the PLOO region. Data are collected over four days during each of these quarterly surveys; see Table 2.1 and text for specific sample dates and stations sampled each day.

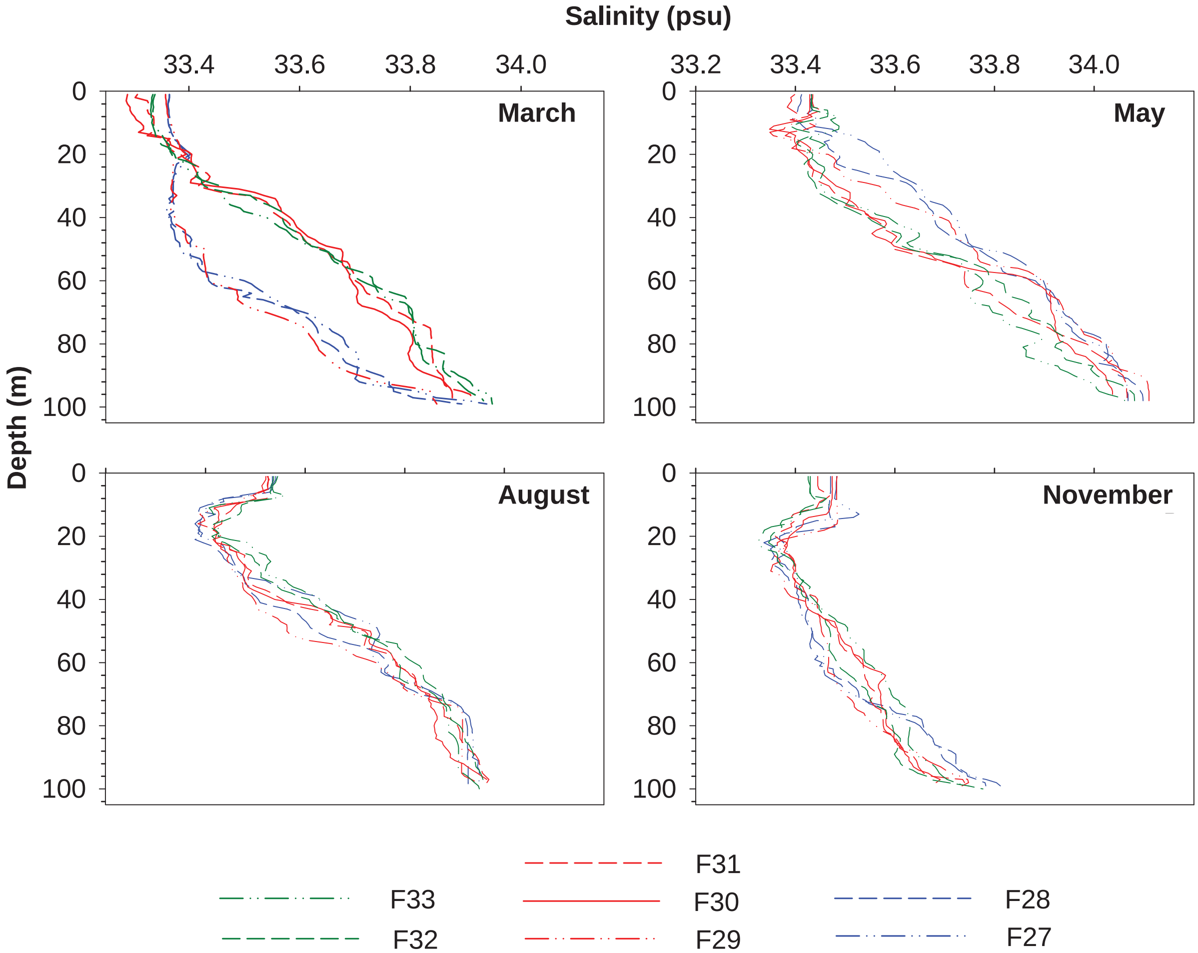


Figure 2.8
Vertical profiles of salinity for PLOO stations F27–F33 during each 2010 quarterly survey.

variability on the north-south axis for all depth bins, with the 11, 35, and 63-m depth bins skewed by a few degrees into the northwest-southeast axis. The 91-m depth bin shows most variability in the north-south axis with the lowest magnitude. The second EOF explains 6.4% of the variability (Appendix A.8A). Most variability is shown on the northwest-southeast axis for the 11, 35, and 68-m depth bins. Similar to the first EOF, the 91-m depth bin in the second EOF shows most variability along the north-south axis.

Spring 2010

Tide-removed data plotted for the spring months in 2010 showed high magnitude currents similar to that observed in winter (Figure 2.10B). The highest magnitude currents occurred in the 11 and 35-m depth bins in a southerly (slightly southeast) direction. However some north and northwest currents were also present in these two depth bins. The 63-m depth bin had lower magnitude currents compared to the 11 and 35-m depth bins, and these currents were in a northwest-southeast direction. The 91-m depth bin had low magnitude currents flowing in a north-south direction during the spring.

The first EOF explains 92.5% of the variability (Figure 2.11B) and shows predominant variability on the north-south axis for the 11, 35, and 63-m depth bins, and is slightly skewed to the northeast-southwest axis. The 91-m depth bin is low in magnitude along the north-south axis. The second EOF explains 6.1% of the variability

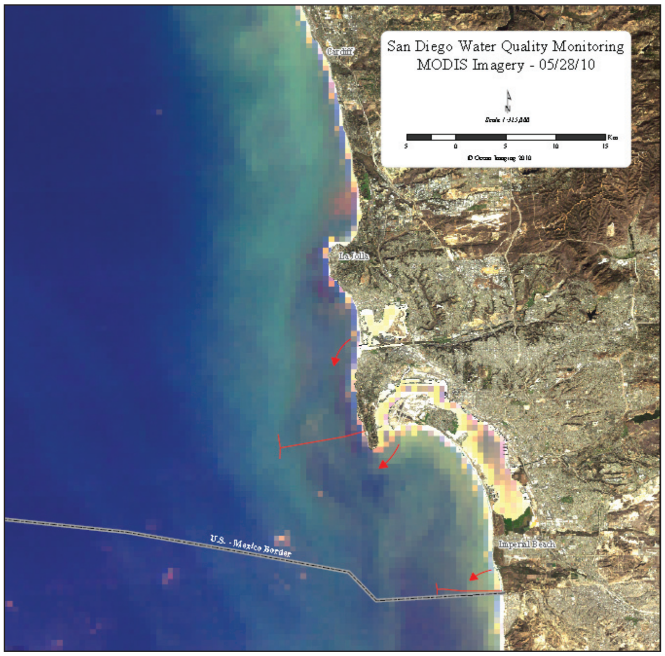


Figure 2.9
MODIS image of the PLOO and coastal region acquired on May 28, 2010, depicting extensive phytoplankton blooms in San Diego's nearshore waters (from Ocean Imaging 2011; see also Svejkovsky 2011).

(Appendix A.8B). Axes for the 11, 35, and 63-m depth bins are north-south, and slightly skewed northwest-southeast.

Summer 2010
Tide-removed data plotted for summer 2010 (Figure 2.10C) showed predominant south and southeast currents in the 11-m depth bin, with some north, northeast and northwest currents. The 35-m depth bin had lower magnitude north-south currents with some east currents. The 63-m depth bin had primarily north and northwest currents. The 91-m depth bin had the lowest magnitude, and its currents were primarily north and northeast.

The first EOF explains 84.8% of the variability (Figure 2.11C). In the 11 and 35-m depth bins, the predominant axis of variability is north-south and slightly in the northwest-southeast axis. Both the 63 and 91-m depth bins are much lower in magnitude. The 63-m depth bin has a southwest-northeast axis, while the 91-m depth bin has a north-south axis. The second EOF explains 14.3% of the variability (Appendix A.8C) and shows predominant variability on or very close to the north-south axis for all depth bins.

Fall 2010
Fall ocean currents were overall the slowest currents in 2010 (Figure 2.10D). Tide-removed data plotted for this season in the 11, 35, and 63-m depth bins showed that all currents were mostly moving in a north-south direction and slightly skewed into the northwest-southeast axis, although there were some smaller magnitude currents in other directions. The 91-m depth bin had most currents flowing north and south with some east currents.

The first EOF explains 77.9% of the variability (Figure 2.11D) and shows the most variability along the north-south axis for the 11 and 35-m depth bins, northeast-southwest axis for the 63-m depth bin, and north-south axis for the 91-m depth bin. The smallest magnitude currents were in the 91-m depth bin. The second EOF explains 19.3% of the variability (Appendix A.8D) and has most variability on the north-south axis in the 11, 63 and 91-m depth bins. The 35-m depth bin is very small in magnitude and has a northwest-southeast axis.

Historical Assessment of Oceanographic Conditions

A review of 20 years (1991–2010) of oceanographic data collected at stations along the 98-m depth contour revealed no significant impacts that could be attributed to wastewater discharge using current methods (Figure 2.12). Although the change from monthly to quarterly sampling in late 2003 has reduced the number of data points for interpretation, results for the region are still consistent with described changes in large-scale patterns in the California Current System (CCS) (Peterson et al. 2006, McClatchie et al. 2008, 2009, Bjokstedt et al. 2010, NOAA 2011). For example, six major events have affected the CCS during the last decade: (1) the 1997–1998 El Niño event; (2) a shift to cold ocean conditions between 1999–2002; (3) a subtle but persistent return to warm ocean conditions beginning in October 2002 that lasted through 2006;

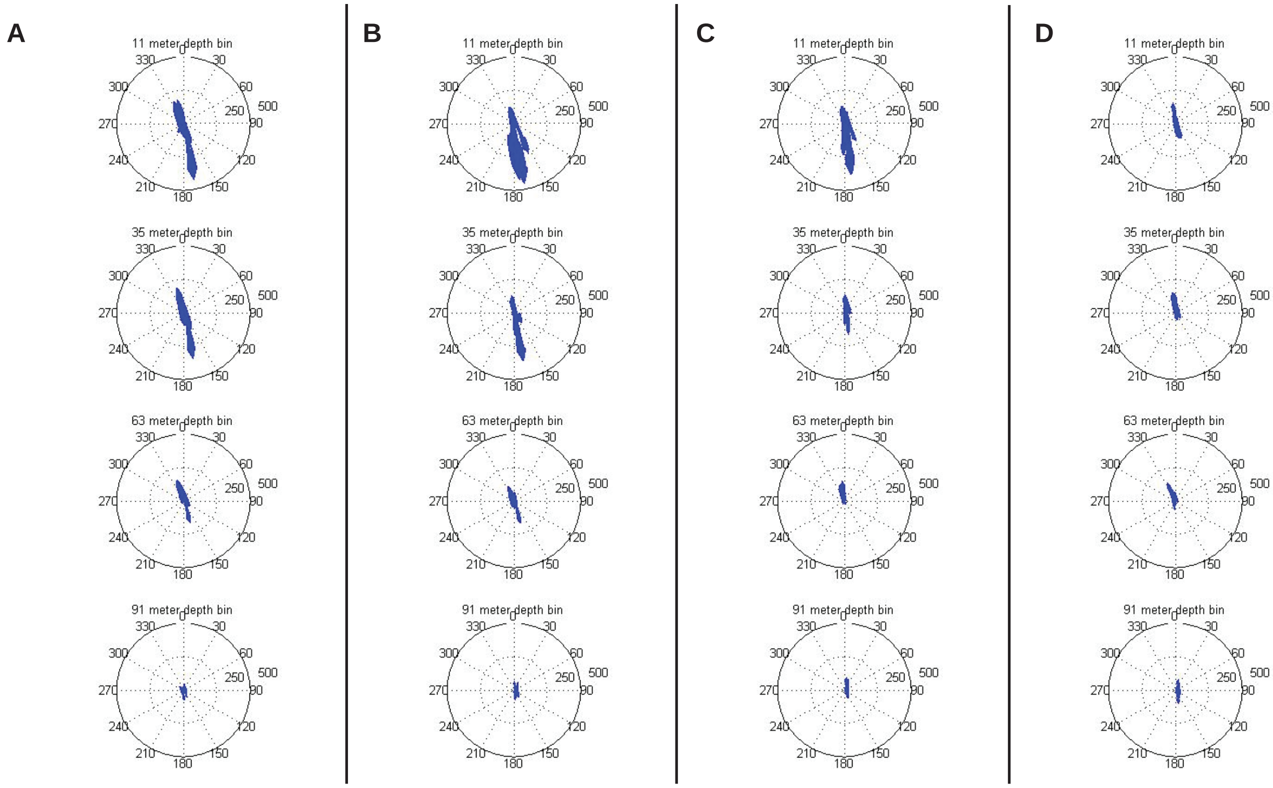


Figure 2.10
Hourly average currents for PLOO on tidally filtered data for (A) winter, (B) spring, (C) summer, and (D) fall during 2010. Arrow length indicates current magnitude (mm/s).

(4) intrusion of subarctic surface waters resulting in lower than normal salinities during 2002–2004; (5) development of a moderate to strong La Niña event in 2007 that coincided with a cooling of the Pacific Decadal Oscillation (PDO); (6) development of a second La Niña event starting in May 2010. Temperature and salinity data for the Point Loma region are consistent with all but the third of these CCS events; i.e., while the CCS was experiencing a warming trend that lasted through 2006, the PLOO region experienced cooler than normal conditions during 2005 and 2006. The conditions in San Diego waters during these two years were more consistent with observations from northern Baja California (Mexico) where water temperatures were well below the decadal mean (Peterson et al. 2006). During 2008 and 2009, temperatures remained cool, but closer to the overall average, whereas 2010 saw the return of cold La Niña conditions.

Water clarity (transmissivity) around the outfall has tended to be higher than the historical average since about mid-1996 (Figure 2.12). This may be due in part to relatively low values that occurred in 1995 and early 1996, perhaps related to factors such as sediment plumes associated with offshore disposal of dredged materials from a large dredging project in San Diego Bay. Subsequent reductions in transmissivity during some winters (e.g., 1998 and 2000) appear to be the result of increased amounts of suspended sediments associated with strong storm activity (e.g., see NOAA/NWS 2010).

There have been no apparent large-scale historical trends in DO concentrations or pH values related to the PLOO discharge (Figure 2.12). These parameters are complex, dependent on water temperature and depth, and sensitive to physico-chemical and biological processes (Skirrow 1975). Moreover, DO and pH are subject to diurnal and seasonal variations that make temporal changes difficult to evaluate. However, DO values below the historical average appear to be related to low levels of chlorophyll or periods of strong upwelling.

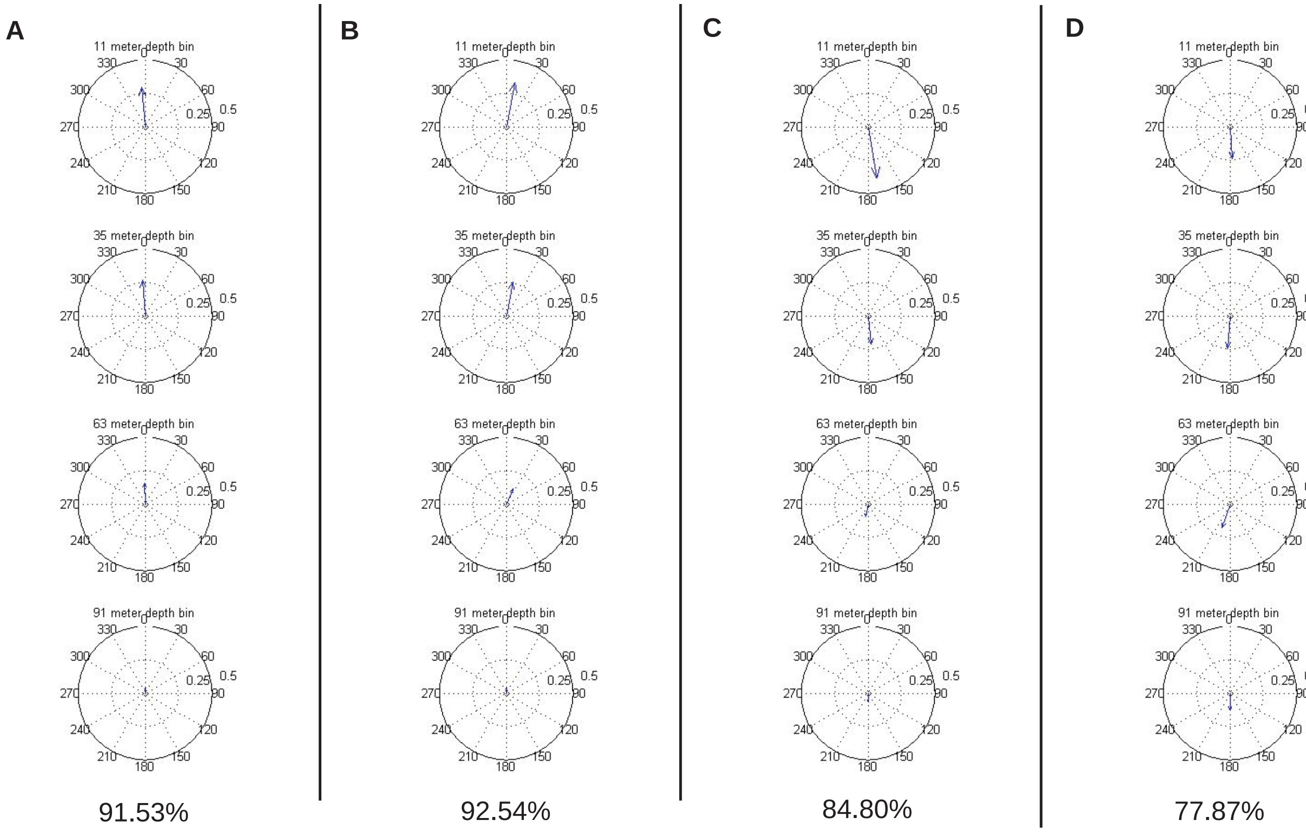


Figure 2.11
Empirical Orthogonal Function 1 (EOF) for (A) winter, (B) spring, (C) summer, and (D) fall in 2010. Percentages indicate fraction of the total variance accounted for by the EOF. Arrow length indicates relative current magnitude.

Discussion

Ocean conditions surrounding the Point Loma outfall in 2010 were generally typical for the region. This included local coastal upwelling and corresponding phytoplankton blooms that were strongest during the spring and summer months and which occurred across the entire region. Upwelling was indicated by relatively cold, dense, saline waters with low DO levels. Phytoplankton blooms were indicated by high chlorophyll concentrations and confirmed by remote sensing observations. Additionally, water column stratification followed patterns typical for San Diego coastal waters, with maximum stratification occurring in mid-summer. Further, oceanographic conditions for the region remained consistent with other well documented large-scale patterns (Peterson et al. 2006, Goericke et al. 2007, McClatchie et al. 2008, 2009, Bjokstedt et al. 2010, NOAA 2011). These observations suggest that other factors such as upwelling of deep ocean waters and large-scale climatic events such as El Niños and La Niñas continue to explain most of the temporal and spatial variability observed in oceanographic parameters off southern San Diego.

Satellite and aerial imagery observations conducted revealed no evidence of the wastewater plume reaching near-surface waters during 2010, even during the winter and fall months when the water column was only weakly stratified (Svejkovsky 2011). This is consistent with results from the bacteriological surveys conducted during the year (see Chapter 3), which also supports the conclusion that the wastefield did not reach surface waters in 2010. Additionally, ocean current measurements recorded in 2010 at sites near the outfall indicated that local currents flowed in northerly and southerly directions throughout most of the year, with some currents directed slightly northwest or southeast. The highest magnitude

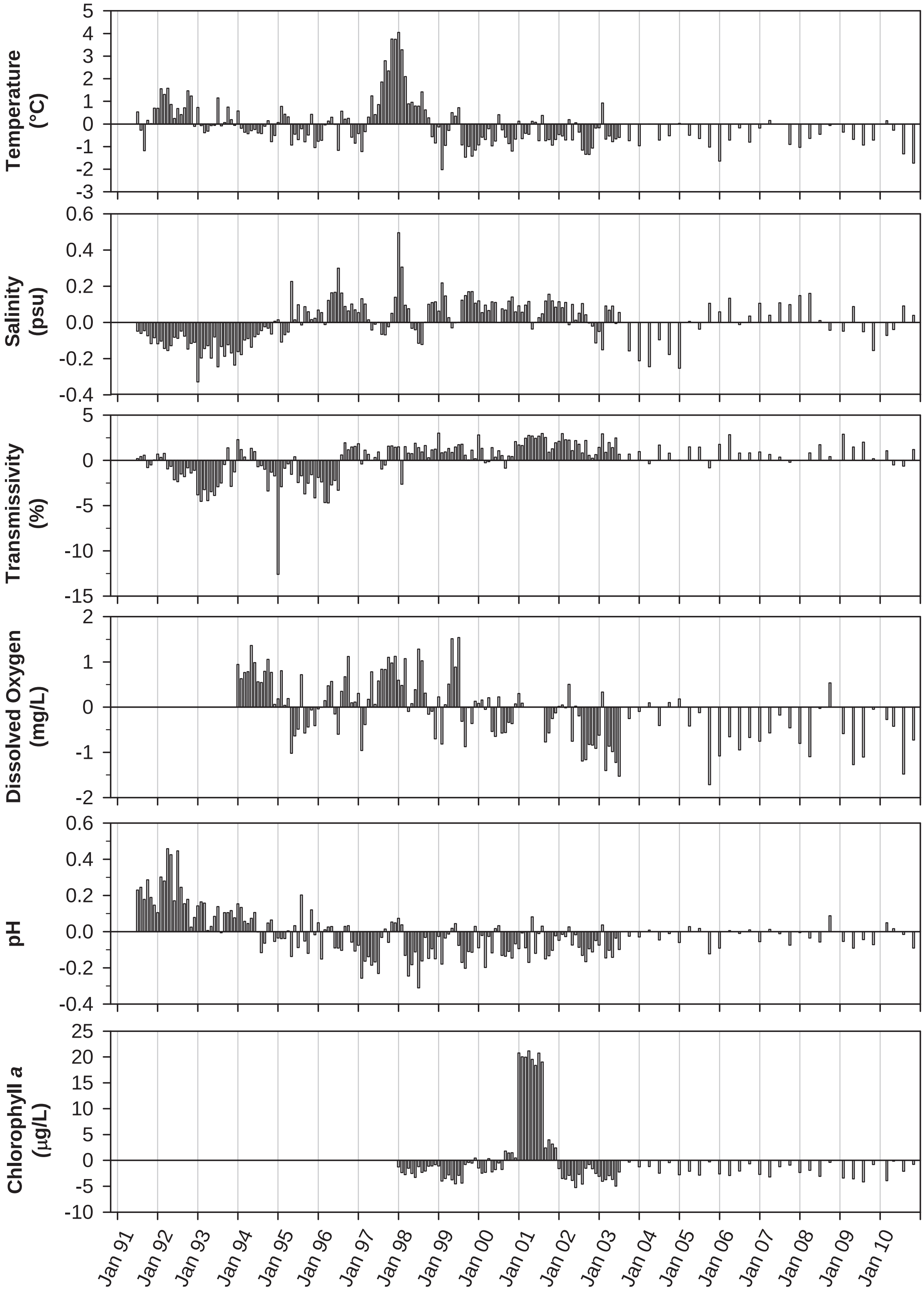


Figure 2.12

Time series of temperature, salinity, transmissivity, dissolved oxygen, pH, and chlorophyll anomalies between 1991 and 2010. Anomalies were calculated by subtracting monthly means for each year (1991–2010) from the mean of all 20 years combined; data were limited to all stations located along the 98-m depth contour, all depths combined.

currents during the year occurred in winter and spring, while the slowest currents occurred in the fall. Consequently, these results indicate that current conditions off Point Loma were not conducive to shoreward transport of the PLOO wastefield at any time during 2010.

Literature Cited

Alessi, C.A., R. Beardsley, R. Limeburner, and L.K. Rosenfeld (1984). CODE-2: Moored Array and Large-Scale Data Report. Woods Hole Oceanographic Institution Technical Report 85-35: 21.

Bowden, K.F. (1975). Oceanic and Estuarine Mixing Processes. In: J.P. Riley and G. Skirrow (eds.). Chemical Oceanography, 2nd Ed., Vol. 1. Academic Press, San Francisco. p 1–41.

Bjorkstedt, E., R. Goericke, S. McClatchie, E. Weber, W. Watson, N. Lo, B. Peterson, B. Emmett, J. Peterson, R. Durazo, G. Gaxiola-Castro, F. Chavez, J.T. Pennington, C.A., Collins, J. Field, S. Ralston, K. Sakuma, S. Bograd, F. Schwing, Y. Xue, W. Sydeman, S.A. Thompson, J.A. Santora, J. Largier, C. Halle, S. Morgan, S.Y. Kim, K. Merkins, J. Hildebrand, and L. Munger. (2010). State of the California Current 2009-2010: Regional variation persists through transition from La Niña to El Niño (and back?). California Cooperative Oceanic Fisheries Investigations (CalCOFI) Reports, 51: 39–69.

City of San Diego. (2010a). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2009. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010b). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2009. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2011). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2011. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Dailey, M.D., D.J. Reish, and J.W. Anderson, eds. (1993). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA.

Dayton, P., P.E. Parnell, L.L. Rasmussen, E.J. Terrill, and T.D. Stebbins. (2009). Point Loma Ocean Outfall Plume Behavior Study, Scope of Work. Scripps Institution of Oceanography, La Jolla, CA, and City of San Diego, Metropolitan Wastewater Department, San Diego, CA. [NOAA Award No. NA08NOS4730441]

Goericke, R., E. Venrick, T. Koslow, W.J. Sydeman, F.B. Schwing, S.J. Bograd, B. Peterson, R. Emmett, K.R. Lara Lara, G. Gaxiola-Castro, J.G. Valdez, K.D. Hyrenbach, R.W. Bradley, M. Weise, J. Harvey, C. Collins, and N. Lo. (2007). The state of the California Current, 2006–2007: Regional and local processes dominate. California Cooperative Oceanic Fisheries Investigations (CalCOFI) Reports, 48: 33–66.

Jackson, G.A. (1986). Physical Oceanography of the Southern California Bight. In: R. Eppley (ed.). Plankton Dynamics of the Southern California Bight. Springer Verlag, New York. p 13–52.

Largier, J., L. Rasmussen, M. Carter, and C. Scearce. (2004). Consent Decree – Phase One Study Final Report. Evaluation of the South Bay International Wastewater Treatment Plant Receiving Water Quality Monitoring Program to Determine Its Ability to Identify Source(s) of Recorded Bacterial Exceedances. Scripps Institution of Oceanography, University of California, San Diego, CA.

Mann, K.H. (1982). Ecology of Coastal Waters, A Systems Approach. University of California Press, Berkeley.

Mann. K.H. and J.R.N. Lazier. (1991). Dynamics of Marine Ecosystems, Biological–Physical Interactions in the Oceans. Blackwell Scientific Publications, Boston.

McClatchie, S., R. Goericke, J.A. Koslow, F.B. Schwing, S.J. Bograd, R. Charter, W. Watson, N. Lo, K. Hill, J. Gottschalck, M. l'Heureux, Y. Xue, W.T. Peterson, R. Emmett, C. Collins, G. Gaxiola-Castro, R. Durazo, M. Kahru, B.G. Mitchell, K.D. Hyrenbach, W.J. Sydeman, R.W. Bradley, P. Warzybok, and E. Bjorkstedt. (2008). The state of the California Current, 2007–2008: La Niña conditions and their effects on the ecosystem. California Cooperative Oceanic Fisheries Investigations (CalCOFI) Reports, 49: 39–76.

McClatchie, S., R. Goericke, J.A. Koslow, F.B. Schwing, S.J. Bograd, R. Charter, W. Watson, N. Lo, K. Hill, J. Gottschalck, M. l'Heureux, Y. Xue, W.T. Peterson, R. Emmett, C. Collins, J. Gomez-Valdes, B.E. Lavaniegos, G. Gaxiola-Castro, B.G. Mitchell, M. Manzano-Sarabia, E. Bjorkstedt. S. Ralston, J. Field, L. Rogers-Bennet, L. Munger, G. Campbell, K. Merkens, D. Camacho, A. Havron, A. Douglas, and J. Hildebrand (2009). The state of the California Current, Spring 2008–2009: Cold conditions drive regional differences in coastal production. California Cooperative Oceanic Fisheries Investigations (CalCOFI) Reports, 50: 43–68.

NOAA/NWS. (2010). The National Oceanic and Atmospheric Association and the National Weather Service Archive of Local Climate Data for San Diego, CA. http://www.wrh.noaa.gov/sgx/obs/rtp/linber.html.

NOAA/NWS. (2011). Climate Prediction Center Website. http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory.html

Ocean Imaging. (2011). Ocean Imaging Corporation archive of aerial and satellite-derived images. http://www.oceani.com/SanDiegoWater/index.html.

[OCSD] Orange County Sanitation District. (1999). Annual Report, July 1998–June 1999. Marine Monitoring, Fountain Valley, CA.

[OCSD] Orange County Sanitation District. (2009). Annual Report, July 2008–June 2009. Marine Monitoring, Fountain Valley, CA.

Parnell, E., and L. Rasmussen. (2010). Summary of PLOO hydrographic observations (2006–2009). Draft report to City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Peterson, B., R. Emmett, R. Goericke, E. Venrick, A. Mantyla, S.J. Bograd, F.B. Schwing, R. Hewitt, N. Lo, W. Watson, J. Barlow, M. Lowry, S. Ralston, K.A. Forney, B.E. Lavaniegos, W.J. Sydeman, D. Hyrenbach, R.W. Bradley, P. Warzybok, F. Chavez, K. Hunter, S. Benson, M. Weise, J. Harvey, G. Gaxiola-Castro, and R. Durazo. (2006). The state of the California Current, 2005–2006: Warm in the north, cool in the south. California Cooperative Oceanic Fisheries Investigations (CalCOFI) Reports, 47: 30–74.

Pickard, D.L. and W.J. Emery. (1990). Descriptive Physical Oceanography. 5th Ed. Pergamon Press, Oxford.

Skirrow, G. (1975). Chapter 9. The Dissolved Gases–Carbon Dioxide. In: Chemical Oceanography. J.P. Riley and G. Skirrow (eds.). Academic Press, London.

Storms, W.E., T.D. Stebbins, and P.E. Parnell. (2006). San Diego Moored Observation

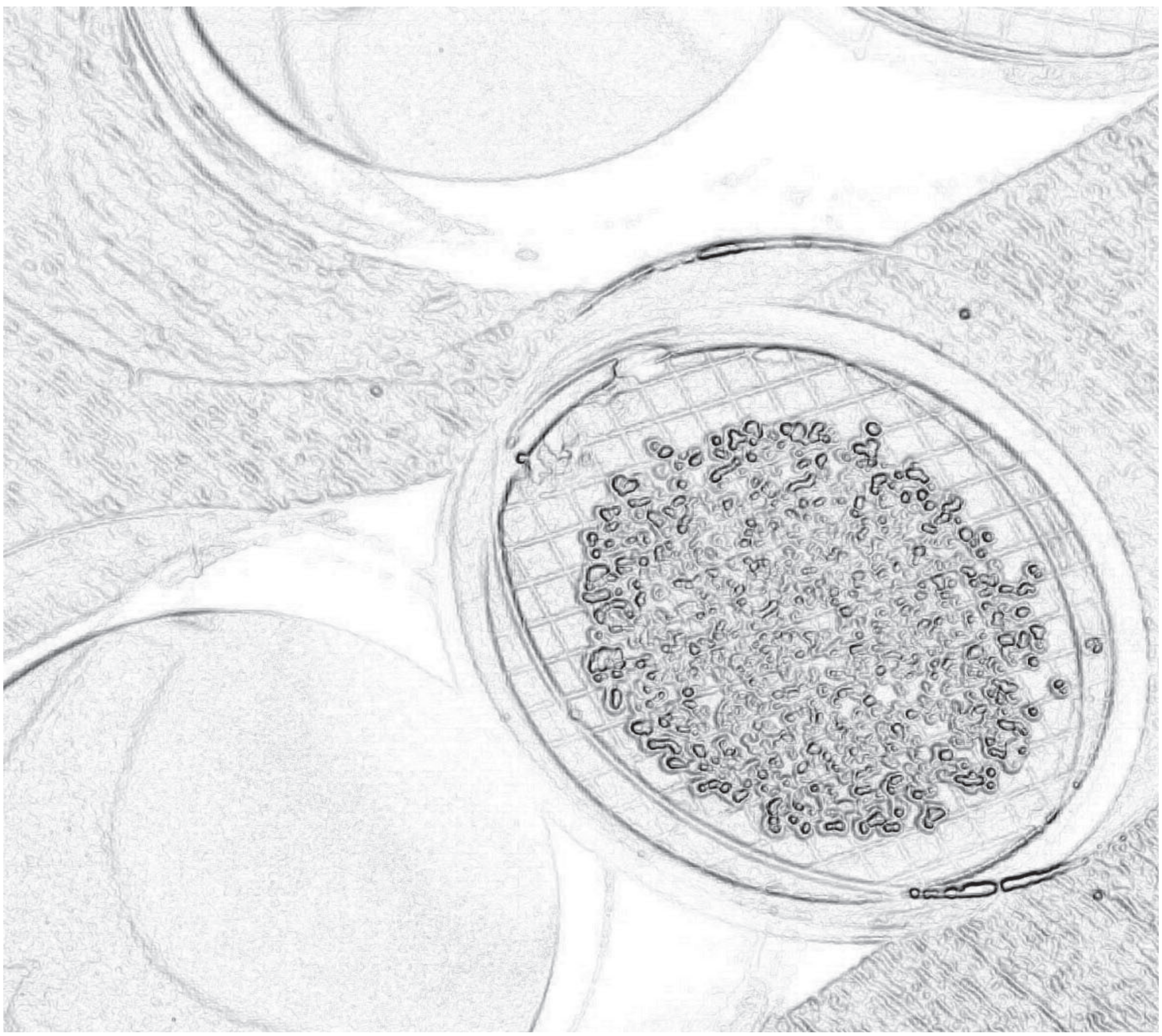
System Pilot Study Workplan for Pilot Study of Thermocline and Current Structure off Point Loma, San Diego, California. City of San Diego, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, and Scripps Institution of Oceanography, La Jolla, CA.

Svejkovsky J. (2011). Satellite and Aerial Coastal Water Quality Monitoring in the San Diego/Tijuana Region: Annual Summary Report for: 1 January 2009 – 31 December 2009. Solana Beach, CA.

Terrill, E., K. Sung Yong, L. Hazard, and M. Otero. (2009). IBWC/Surfrider – Consent Decree Final Report. Coastal Observations and Monitoring in South Bay San Diego. Scripps Institution of Oceanography, University of California, San Diego, CA.

This page intentionally left blank

Chapter 3
Water Quality



Chapter 3. Water Quality

Introduction

The City of San Diego collects and analyzes seawater samples from along the shoreline and in offshore ocean waters of the region surrounding the Point Loma Ocean Outfall (PLOO) to characterize water quality conditions in the region and to identify possible impacts of wastewater discharge on the marine environment. Densities of fecal indicator bacteria (FIB), including total coliforms, fecal coliforms, and enterococcus, are measured and evaluated along with data on local oceanographic conditions (see Chapter 2) to provide information about the movement and dispersion of wastewater discharged into the Pacific Ocean through the outfall. Evaluation of these data may also help to identify other point or non-point sources of bacterial contamination. In addition, the City's water quality monitoring program is designed to assess compliance with water contact standards as established in the California Ocean Plan (Ocean Plan), which defines bacterial water quality objectives and standards with the intent of protecting the beneficial uses of State ocean waters (SWRCB 2001, 2005).

Because there are multiple natural and anthropogenic point and non-point sources that can impact water quality, distinguishing a wastewater plume from other sources of bacterial contamination in ocean waters is often challenging. In the PLOO region, multiple sources of potential bacterial contamination exist in addition to the outfall itself, including tidal exchange from San Diego Bay, outflows from the Tijuana River, the San Diego River and coastal lagoons in northern San Diego County, storm water discharges, and runoff from local watersheds (Noble et al. 2003, Griffith et al. 2009, Svejkovsky 2011). Likewise, it has been shown that kelp and seagrass beach wracks, storm drains impacted by tidal flushing, and beach sediments can act as reservoirs, cultivating bacteria until high tide returns and/or other disturbances release them into nearshore waters (Gruber et al. 2005, Martin and Gruber 2005). Finally, the presence of birds and their droppings have been related to bacterial exceedances that may impact nearshore water quality (Grant et al. 2001, Griffith et al. 2009).

This chapter presents analyses and interpretation of FIB densities and ammonia data collected during 2010 at monitoring sites surrounding the PLOO. The primary goals are to: (1) evaluate overall water quality conditions in the region, (2) differentiate among various sources of bacterial contamination in the survey area, including the PLOO wastewater plume, (3) evaluate potential movement and dispersal of wastewater discharged via the PLOO, and (4) assess compliance with water contact standards as defined in the Ocean Plan.

Materials and Methods

Field Sampling

Shore stations

Seawater samples for bacteriological analyses were collected at eight shore stations (i.e., stations D4, D5, and D7–D12; Figure 3.1) to monitor FIB concentrations in waters adjacent to public beaches and to evaluate compliance with Ocean Plan water contact standards (see Box 3.1). Seawater samples were collected from the surf zone in sterile 250-mL bottles at each station five times during the month. In addition, visual observations of water color, surf height, human or animal activity, and weather conditions were recorded at the time of collection. The samples were then transported on blue ice to the City of San Diego's Marine Microbiology Laboratory (CSDMML) and analyzed to determine concentrations of total coliform, fecal coliform, and enterococcus bacteria.

Kelp bed and offshore stations

Eight stations located in nearshore waters within the Point Loma kelp forest were sampled weekly to assess water quality conditions and Ocean Plan

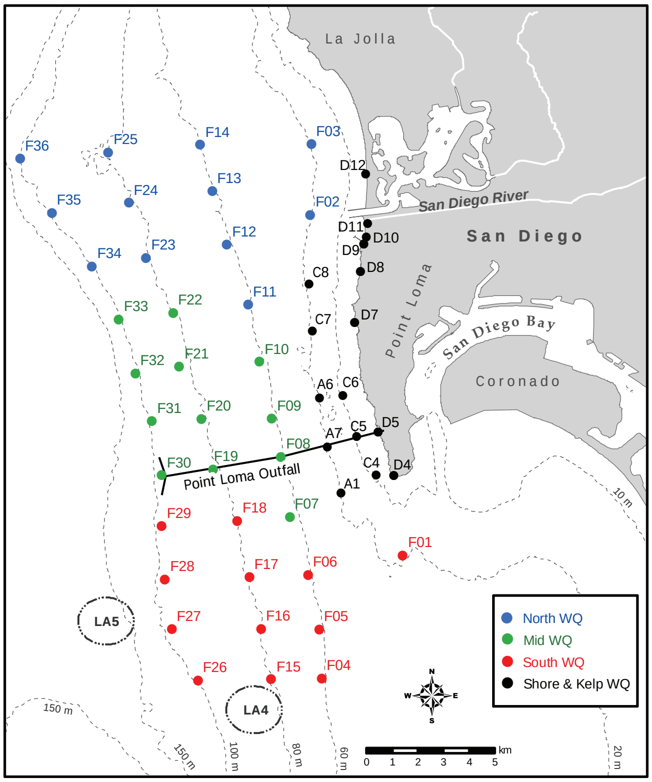


Figure 3.1
Water quality (WQ) monitoring stations for the Point Loma Ocean Outfall Monitoring Program.

compliance in areas used for recreational activities such as SCUBA diving, surfing, fishing, and kayaking. These included stations C4, C5 and C6 located near the inner edge of the kelp bed along the 9-m depth contour, and stations A1, A6, A7, C7 and C8 located near the outer edge of the kelp bed along the 18-m depth contour (Figure 3.1). As at the shore stations, weekly monitoring at each of the kelp bed sites primarily consisted of collecting seawater samples to determine concentrations of total coliform, fecal coliform, and enterococcus bacteria. Starting in August, samples for ammonia analysis were collected at these same sites on a quarterly basis to correspond with sampling at the offshore stations located within State waters (see below). During the last quarter of 2010, however, the quarterly ammonia samples for these eight sites were collected during December instead due to a sampling oversight the previous month.

An additional 36 stations located further offshore were sampled in order to monitor FIB levels in these deeper waters and to estimate dispersion of the wastewater plume. These offshore stations are arranged in a grid surrounding the discharge site along or adjacent to the 18, 60, 80, and 98-m depth contours (Figure 3.1). In contrast to shore and kelp bed stations, monitoring at all offshore sites was conducted on a quarterly basis, typically during the months of February, May, August and November, with each survey usually occurring over a 3-day period. However, sampling during the first quarter of 2010 was delayed until March to accommodate a Bight'08 Water Quality Survey that was postponed until this year (see Table 2.1 for the specific dates each survey was conducted). For the first half of 2010 (i.e., March and May), samples collected from these sites were analyzed for densities of total coliform, fecal coliform, and enterococcus; however, analyses of these samples were limited to enterococcus only following the transition to bacterial compliance standards specified in the 2005 Ocean Plan which became effective August 1, 2010 (see Data Treatment section below). At the same time, monitoring for ammonia began at the same discrete depths where bacterial samples were collected at the 15 offshore stations located within State jurisdictional waters (i.e., within 3 nautical miles of shore).

Seawater samples for the kelp and offshore stations were collected at 3–5 discrete depths per site dependent upon station depth (see Table 3.1). These samples were collected using either an array of Van Dorn bottles or a rosette sample fitted with Niskin bottles. Aliquots for ammonia and bacteriological analyses were drawn from these bottles into sterile sample bottles for processing at the City's Toxicology Laboratory and CSDMML, respectively. Visual observations of weather and sea conditions, and human or animal activity were also recorded at the time of sampling.

Laboratory Analyses

All bacterial analyses were performed within 8 hours of sample collection and conformed to standard membrane filtration techniques (APHA 1998). The CSDMML follows guidelines issued by the United States Environmental Protection Agency (USEPA)

Box 3.1

Bacteriological compliance standards for water contact areas, 2001 California Ocean Plan (SWRCB 2001). CFU = colony forming units.

(a) *30-day Total Coliform Standard* — no more than 20% of the samples at a given station in any 30-day period may exceed a concentration of 1000 CFU per 100 mL.

(b) *10,000 Total Coliform Standard* — no single sample, when verified by a repeat sample collected within 48 hrs, may exceed a concentration of 10,000 CFU per 100 mL.

(c) *60-day Fecal Coliform Standard* — no more than 10% of the samples at a given station in any 60-day period may exceed a concentration of 400 CFU per 100 mL.

(d) *30-day Fecal Geometric Mean Standard* — the geometric mean of the fecal coliform concentration at any given station in any 30-day period may not exceed 200 CFU per 100 mL, based on no fewer than five samples.

Bacteriological compliance standards for water contact areas, 2005 California Ocean Plan (SWRCB 2005). CFU = colony forming units.

(a) *30-day Geometric Mean* — The following standards are based on the geometric mean of the five most recent samples from each site:
   1) Total coliform density shall not exceed 1000 CFU/100 mL.
   2) Fecal coliform density shall not exceed 200 CFU/100 mL.
   3) Enterococcus density shall not exceed 35 CFU/100 mL.

(b) *Single Sample Maximum*:
   1) Total coliform density shall not exceed 10,000 CFU/100 mL.
   2) Fecal coliform density shall not exceed 400 CFU/100 mL.
   3) Enterococcus density shall not exceed 104 CFU/100 mL.
   4) Total coliform density shall not exceed 1000 CFU/100 mL when the fecal coliform:total coliform ratio exceeds 0.1.

Water Quality Office, Water Hygiene Division, and the California State Department of Health Services (CDHS) Environmental Laboratory Accreditation Program (ELAP) with respect to sampling and analytical procedures (Bordner et al. 1978, APHA 1998).

Procedures for counting colonies of indicator bacteria, calculation and interpretation of results, data verification and reporting all follow guidelines established by the USEPA (Bordner et al. 1978) and APHA (1998). According to these guidelines, plates with FIB counts above or below the ideal counting range were given greater than (>), less than (<), or estimated (e) qualifiers. However, these qualifiers were dropped and the counts treated as discrete values when calculating means and in determining compliance with Ocean Plan standards.

Quality assurance (QA) tests were performed routinely on seawater samples to ensure that sampling variability did not exceed acceptable limits. Duplicate and split bacteriological samples were processed according to method requirements to measure intra-sample and inter-analyst variability, respectively. Results of these procedures were reported in City of San Diego (2011a).

Additional seawater samples were analyzed for ammonia (as nitrogen) by the Salicylate Method using a Hach DR850 colorimeter. Quality assurance tests for these analyses were performed using blanks.

Data Treatment

FIB densities were summarized as monthly averages for each shore station and by depth contour for the

Table 3.1
Depths at which seawater samples are collected for bacteriological analysis at the PLOO kelp bed and offshore stations.

Station Contour	Sample Depth (m) 1	3	9	12	18	25	60	80	98
Kelp Bed									
9-m	x	x	x						
18-m	x			x	x				
Offshore									
18-m	x			x	x				
60-m	x					x	x		
80-m	x					x	x	x	
98-m	x					x	x	x	x

kelp stations. To assess temporal and spatial trends, bacteriological data were summarized as counts of samples in which FIB concentrations exceeded benchmark levels. For this report, water contact limits defined in the 2005 Ocean Plan for densities of total coliforms, fecal coliforms, and enterococcus in individual samples (i.e., single sample maxima; see Box 3.1 and SWRCB 2005) were used as reference points to distinguish elevated FIB values (or benchmarks). Concentrations of each FIB are identified by sample in Appendices B.1, B.2, and B.3. In addition, the 2005 Ocean Plan single sample maximum standard that states total coliform densities shall not exceed 1000 CFU/100 mL when the fecal coliform:total coliform (F:T) ratio exceeds 0.1 was considered as the criterion for contaminated waters. This condition is referred to as the fecal:total ratio (FTR) criterion herein. Since enterococcus was the only type of bacteria measured in samples from the 36 offshore sites between August and December (see above), analyses were limited to this parameter for the entire year. Finally, Pearson's Chi-Square analyses (χ^2) were conducted to determine if the frequency of samples with elevated FIBs differed between wet versus dry seasons.

Compliance with Ocean Plan water-contact standards was summarized as the number of days that each of the shore stations and all of the kelp bed stations exceeded various Ocean Plan standards during each month. Due to regulatory changes that became effective August 1, 2010, bacterial compliance was assessed using the water contact standards specified in the 2001 Ocean Plan (Box 3.1 and SWRCB 2001) between January 1 and July 31, 2010, whereas data collected after August 1, 2010 were assessed using the standards specified in the 2005 Ocean Plan (Box 3.1 and SWRCB 2005).

Results

Distribution of FIBs

Shore stations

As in previous years, concentrations of indicator bacteria were generally low along the Point Loma shoreline in 2010. Monthly FIB densities at the individual shore stations averaged from 2 to 3254 CFU/100 mL for total coliforms, 2 to 93 CFU/100 mL for fecal coliforms, and 2 to 149 CFU/100 mL for enterococcus (Table 3.2). As expected, the highest values for each parameter occurred between January–April and October–December when rainfall totaled 16.2 inches (vs. 0.08 inches in the dry season). In fact, each of the 12 shore station samples with elevated FIBs and each of the two samples that exceeded the FTR criterion were collected during these wet season months (Table 3.3, Appendix B.1) when rain events cause turbidity plumes that can impact the area. For example, a Rapid Eye satellite image taken December 24, 2010 showed turbidity plumes encompassing several of the shore stations, seven of which had elevated enterococcus concentrations on the previous day (Figure 3.2). While the image in this figure was not taken on the same day the bacterial samples were collected, the turbidity plume that is evident likely started earlier in the week due to a large storm that began December 21, 2010. This general relationship between rainfall and elevated bacteria levels has been somewhat evident over the past several years (Figure 3.3); these data indicate that there is 5% greater chance of collecting a sample with elevated FIBs during the wet season than during the dry season [$\chi^2(1, N = 1963) = 19.9, p < 0.001$].

Table 3.2

Summary of rainfall and bacteria levels at PLOO shore stations during 2010. Total coliform, fecal coliform, and enterococcus densities are expressed as mean CFU/100 mL per month and for the entire year. Rain data are from Lindbergh Field, San Diego, CA. Stations are listed north to south from top to bottom; *n* = total number of samples.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010 Total Rain (in)		3.38	2.30	0.68	1.78	0.01	0.02	0.02	0.00	0.03	2.18	0.88	5.00
D12	*Total*	157	129	9	4	16	28	26	16	13	672	131	264
	Fecal	8	4	2	2	2	3	2	5	2	29	7	23
	Entero	20	3	2	2	2	4	4	2	3	43	7	123
D11	*Total*	200	3254	1260	1864	44	20	28	16	34	145	272	652
	Fecal	13	70	33	54	15	4	6	7	4	8	8	30
	Entero	30	122	14	6	16	22	16	3	6	12	14	83
D10	*Total*	505	101	172	116	20	32	30	17	80	40	300	452
	Fecal	6	4	12	8	3	5	3	2	6	5	20	14
	Entero	25	4	5	3	2	2	2	2	18	8	31	38
D9	*Total*	44	538	156	25	32	56	66	17	13	28	96	129
	Fecal	2	12	5	2	2	2	3	2	2	4	10	8
	Entero	4	15	4	2	7	2	2	2	2	16	10	28
D8	*Total*	ns	ns	ns	ns	252	60	20	49	96	125	328	352
	Fecal	ns	ns	ns	ns	2	2	2	4	8	93	43	51
	Entero	ns	ns	ns	ns	2	2	4	2	7	40	15	77
D7	*Total*	80	53	11	2	14	52	58	124	95	120	28	216
	Fecal	3	2	2	2	2	2	2	7	9	71	11	28
	Entero	13	2	2	2	2	3	3	5	2	149	4	76
D5	*Total*	66	90	8	9	16	16	20	13	56	256	232	456
	Fecal	5	2	2	2	2	2	2	2	2	27	6	54
	Entero	2	2	2	2	2	2	2	2	2	2	22	107
D4	*Total*	41	9	6	4	9	46	31	16	44	96	49	1125
	Fecal	4	2	2	2	2	2	2	3	3	3	8	63
	Entero	2	2	2	2	2	2	2	2	5	2	3	58
	n	33	35	35	35	40	40	48	40	40	40	40	40
Annual Means	*Total*	156	596	232	289	50	39	35	34	54	185	180	456
	Fecal	6	14	8	10	4	3	3	4	5	30	14	34
	Entero	14	21	4	3	4	5	4	3	6	34	13	74

ns = not sampled (no samples were collected at station D8 from January 1 to April 26 due to shoreline inaccessibility)

Kelp bed stations

Concentrations of indicator bacteria were also generally low at the eight kelp bed stations in 2010. For example, monthly FIB densities at these stations averaged about 2 to 232 CFU/100 mL for total coliforms, 2 to 5 CFU/100 mL for fecal coliforms, and 2 to 45 CFU/100 mL for enterococcus (Table 3.4). Of the 1431 seawater samples collected from these sites during the year, only six samples (0.4%) had elevated FIBs and none of the samples

Table 3.3

The number of samples with elevated bacteria densities collected at PLOO shore stations during 2010. Elevated FIB = total number of samples with elevated FIBs; contaminated = total number of samples that meet the fecal:total coliform ratio criterion indicative of contaminated waters; wet season = January–April and October–December; dry season = May–September; *n* = total number of samples. Rain data are from Lindbergh Field, San Diego, CA. Stations are listed north to south from top to bottom.

Station		Season Wet	Season Dry	% Wet
D12	Elevated FIB	2	0	100
	Contaminated	0	0	—
D11	Elevated FIB	2	0	100
	Contaminated	0	0	—
D10	Elevated FIB	2	0	100
	Contaminated	0	0	—
D9	Elevated FIB	0	0	—
	Contaminated	0	0	—
D8	Elevated FIB	2	0	100
	Contaminated	1	0	100
D7	Elevated FIB	2	0	100
	Contaminated	0	0	100
D5	Elevated FIB	1	0	100
	Contaminated	1	0	100
D4	Elevated FIB	1	0	100
	Contaminated	0	0	—
	Rain (in)	16.20	0.08	
Total	Elevated FIB	12	0	100
Counts	Contaminated	2	0	100
	n	258	208	

exceeded the FTR criterion (Appendix B.2). Half of the samples with elevated FIBs were collected in the wet season and may have been associated with rainfall events (Table 3.5). The source of contamination in the three samples with elevated FIBs collected in the dry season remains unclear.

Offshore stations

Concentrations of enterococcus bacteria reached 920 CFU/100 mL in samples collected from the 36 offshore stations during 2010 (Appendix B.3). However, only 15 of 564 samples (~2.7%) had elevated enterococcus levels, all of which were collected at depths ≥60 m from just six stations located along the 80 and 98-m depth contours (Figure 3.4). These results suggest that the

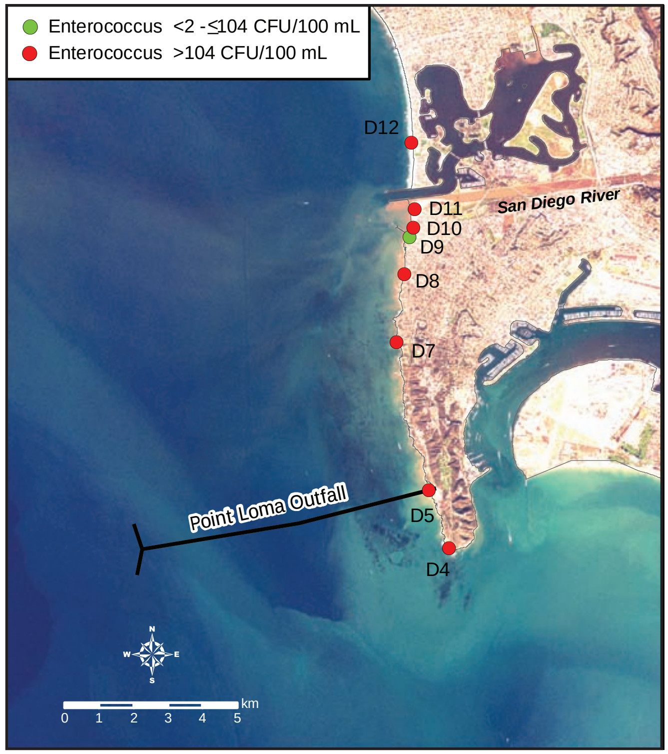


Figure 3.2

Rapid Eye satellite image showing the PLOO monitoring region on December 24, 2010 (Ocean Imaging 2011) combined with enterococcus concentrations at shore stations sampled on December 22, 2010. Turbid waters from the San Diego River, San Diego Bay, and from other sources to the south can be seen overlapping PLOO shore stations.

wastewater plume remained restricted to relatively deep, offshore waters throughout the year and are consistent with remote sensing observations that provided no evidence of the plume reaching surface waters in 2010 (Svejkovsky 2011).

California Ocean Plan Compliance

Overall compliance with Ocean Plan standards in 2010 was 99.7%. Compliance was lowest in January–March and October–December when rainfall was greatest. During the first seven months of the year (i.e., January–July), all eight kelp bed and six of the eight shore stations were in complete compliance with all four of the 2001 Ocean Plan standards (Appendix B.4). Only shore stations D8 and D11 fell below 100% compliance, with all but one of the exceedances occurring during the wet season. For example, the 30-day total coliform standard was exceeded at station D8 in January

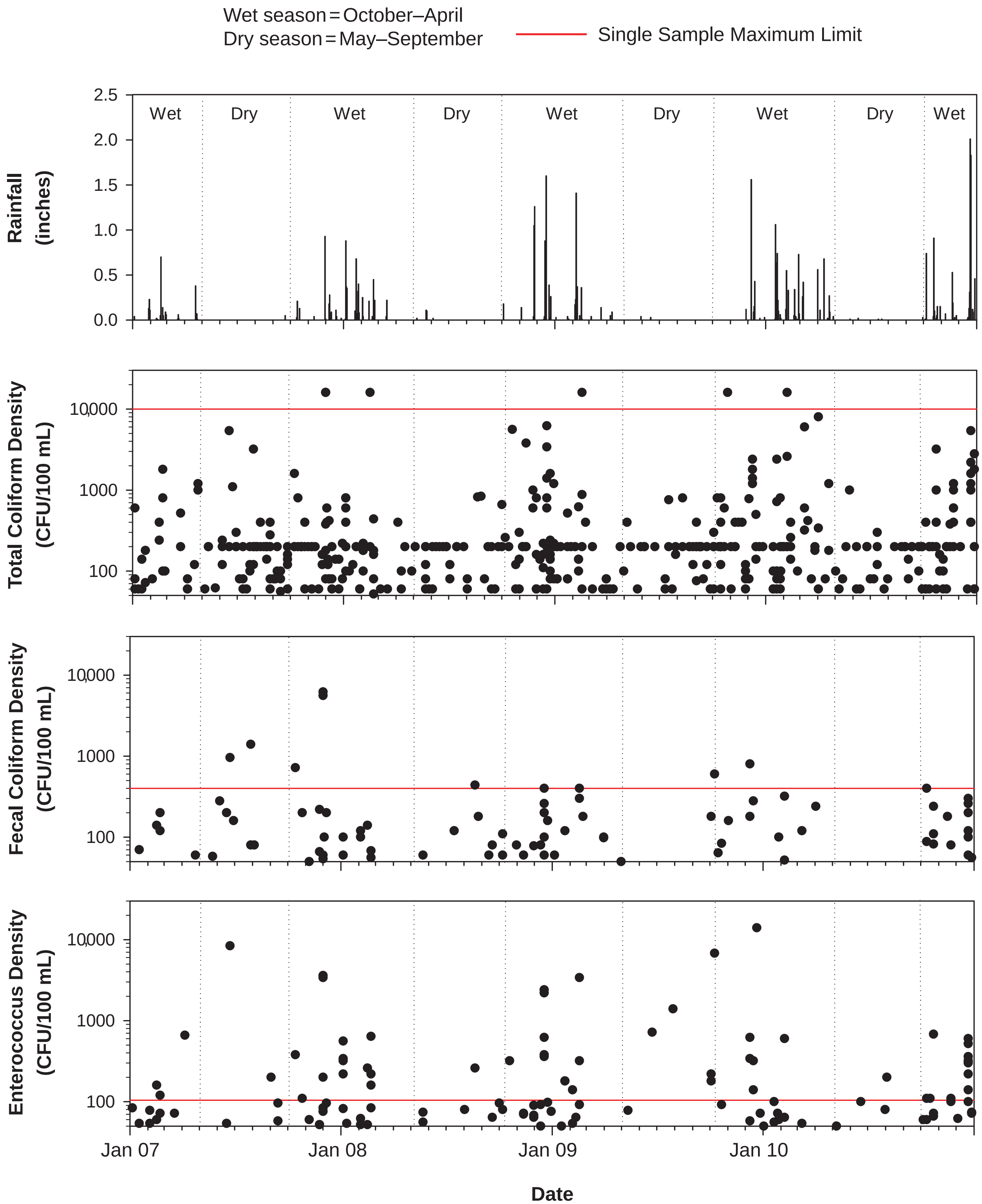


Figure 3.3
Comparison of bacteriological data from PLOO shore stations to rainfall between January 1, 2007 and December 31, 2010. Densities of bacteria have been limited to ≥ 50 CFU/100mL for clearer data presentation.

Table 3.4

Summary of FIB densities (CFU/100 mL) at PLOO kelp bed stations in 2010. Total coliform, fecal coliform, and enterococcus data are expressed as means for all stations along each depth contour by month; *n* = total number of samples per month.

Assay	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
9-m Depth Contour												
Total	4	2	3	3	3	6	4	4	3	8	10	11
Fecal	2	2	2	2	2	2	2	2	2	2	2	2
Entero	3	2	8	2	2	2	2	2	2	2	2	2
n	45	36	45	45	45	45	45	45	45	45	45	45
18-m Depth Contour												
Total	31	10	34	10	25	4	16	6	5	16	232	20
Fecal	3	2	4	3	2	2	3	2	2	2	5	2
Entero	8	2	45	3	15	2	2	5	2	2	2	3
n	75	75	75	75	75	75	75	75	75	75	75	75

and at station D11 during February, March, April and May, which resulted in 97% and 77% overall compliance with this standard, respectively. During the last five months of the year (i.e., August–December), all of the kelp bed and all but one of the shore stations were in complete compliance with the 2005 Ocean Plan 30-day geometric mean standards for total coliforms, fecal coliforms, and enterococcus (Appendix B.5). The only exception occurred at shore station D11 in December. Additionally, the four single sample maximum (SSM) standards in the 2005 Ocean Plan were exceeded just once at the kelp bed stations (i.e., the total coliform SSM exceedance at station A7 in November), while all of the offshore stations within State waters were in complete compliance with the SSM for enterococcus. While the SSMs for total and fecal coliform bacteria were never exceeded at the shore stations during the latter part of 2010, and the FTR was only exceeded twice in December (once each at D5 and D8), several of the shore stations exceeded the SSM for enterococcus during October, November and December.

Ammonia was detected in 48% of the 144 samples collected from PLOO stations in 2010 at concentrations up to 0.16 mg/L. These ammonia levels were substantially lower than the water quality objectives defined in the 2005 Ocean Plan (i.e., instant maximum of 6.0 mg/L, daily maximum of 2.4 mg/L; SWRCB 2005). Overall, ammonia was found in samples from 22 of 23 stations surveyed during August (Figure 3.5). The highest concentration was detected in surface water at station F02 located offshore of the mouth of the San Diego River and Mission Bay. Other relatively high ammonia concentrations >0.10 mg/L were also detected throughout the water column at kelp bed stations C4, A1, A7 and A6 and at offshore stations F8, F9 and F19. Ammonia was detected less frequently during the fourth quarter, occurring at only six stations and at concentrations below 0.07 mg/L. None of the samples with detectable concentrations of ammonia contained elevated concentrations of enterococcus bacteria (Figure 3.4; City of San Diego 2011b).

Discussion

Water quality conditions in the Point Loma outfall region were excellent during 2010, as indicated by an overall 99.7% compliance rate with Ocean Plan water-contact standards. In addition, there was no evidence during the year that wastewater discharged to the ocean via the PLOO reached the shoreline or nearshore recreational waters. Although elevated FIB densities were detected occasionally along the shoreline and at the kelp bed stations, concentrations of these bacteria tended to be relatively low overall. In fact, only two of the seawater samples collected during the year met

Table 3.5
The number of samples with elevated bacteria collected at PLOO kelp bed stations during 2010. Elevated FIB = total number of samples with elevated FIBs; contaminated = total number of samples that meet the fecal:total coliform ratio criterion indicative of contaminated waters; wet season = January–April and October–December; dry season = May–September; *n* = total number of samples. Rain data are from Lindbergh Field, San Diego, CA.

Station		Season Wet	Season Dry	% Wet
9-m Depth Contour				
C6	Elevated FIB	0	0	—
	Contaminated	0	0	—
C5	Elevated FIB	0	0	—
	Contaminated	0	0	—
C4	Elevated FIB	1	0	100
	Contaminated	0	0	—
18-m Depth Contour				
A6	Elevated FIB	0	1	0
	Contaminated	0	0	—
A7	Elevated FIB	1	2	33
	Contaminated	0	0	—
A1	Elevated FIB	1	0	100
	Contaminated	0	0	100
C8	Elevated FIB	0	0	—
	Contaminated	0	0	—
C7	Elevated FIB	0	0	—
	Contaminated	0	0	—
	Rain (in)	16.20	0.08	
Total	Elevated FIB	3	3	50
Counts	Contaminated	0	0	100
	n	831	600	

the FTR criterion for contaminated waters, and no samples had elevated levels of fecal coliform bacteria. Over the years, elevated FIBs detected at shore and kelp bed stations have tended to be associated with rainfall events, heavy recreational use, or the presence of seabirds or decaying kelp and surfgrass (e.g., City of San Diego 2009). During 2010, all of the elevated bacterial densities along the shore occurred between the months January–April and October–December, during which time there was a total of 16.2 inches of rain.

Previous analyses of water quality data for the region have indicated that the PLOO wastefield has typically remained well offshore and submerged in deep waters since the extension of the outfall was completed in late 1993 (City of San Diego 2007, 2008, 2009, 2010a). This pattern remained true for 2010 with evidence of the wastewater plume restricted to depths of 60 m or below in offshore waters. Moreover, no visual evidence of the plume surfacing was detected in aerial or satellite imagery during 2010 (Svejkovsky 2011). The deepwater (98 m) location of the discharge site may be the dominant factor that inhibits the plume from reaching surface waters. For example, wastewater released into these deep, cold and dense waters does not appear to mix with the top 25 m of the water column. Finally, it appears that not only is the plume from the PLOO being trapped below the thermocline, but now that effluent is undergoing chlorination prior to discharge, densities of indicator bacteria in local receiving waters have dropped substantially (see City of San Diego 2010a).

Literature Cited

[APHA] American Public Health Association. (1998). Standard Methods for the Examination of Water and Wastewater, 18th edition. A.E. Greenberg, L.S. Clesceri, and A.D. Eaton (eds.). American Public Health Association, American Water Works Association, and Water Pollution Control Federation.

Bordner, R., J. Winter, and P. Scarpino, eds. (1978). Microbiological Methods for Monitoring the Environment: Water and Wastes, EPA Research and Development, EPA-600/8-78-017.

City of San Diego. (2007). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2006. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2008). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2007. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater

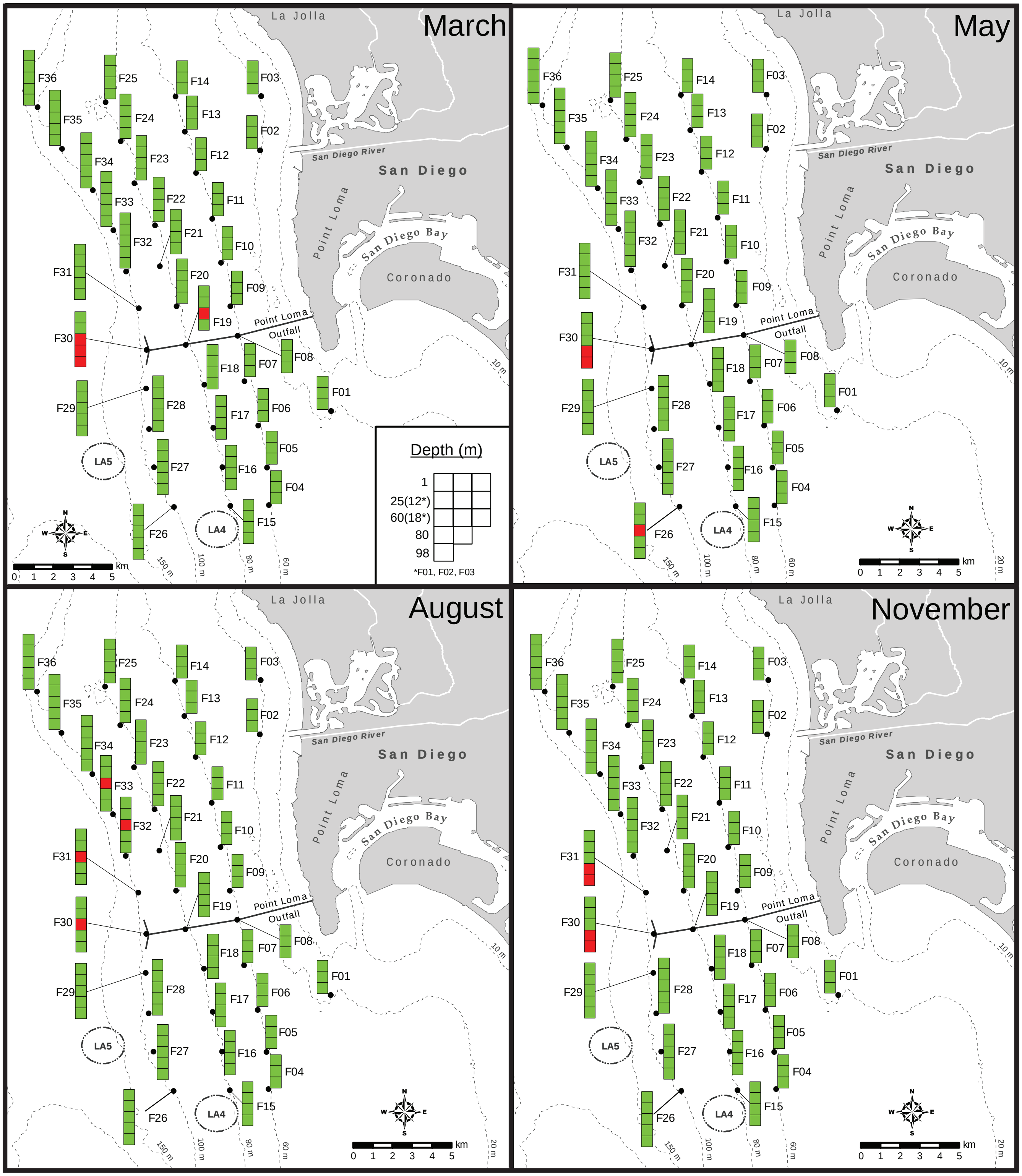


Figure 3.4
Distribution of seawater samples collected during the PLOO quarterly surveys in 2010 that contained elevated densities of enterococcus (i.e., >104 CFU/100 mL; red squares). See text and Table 2.1 for sampling details.

Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2009). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2008. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

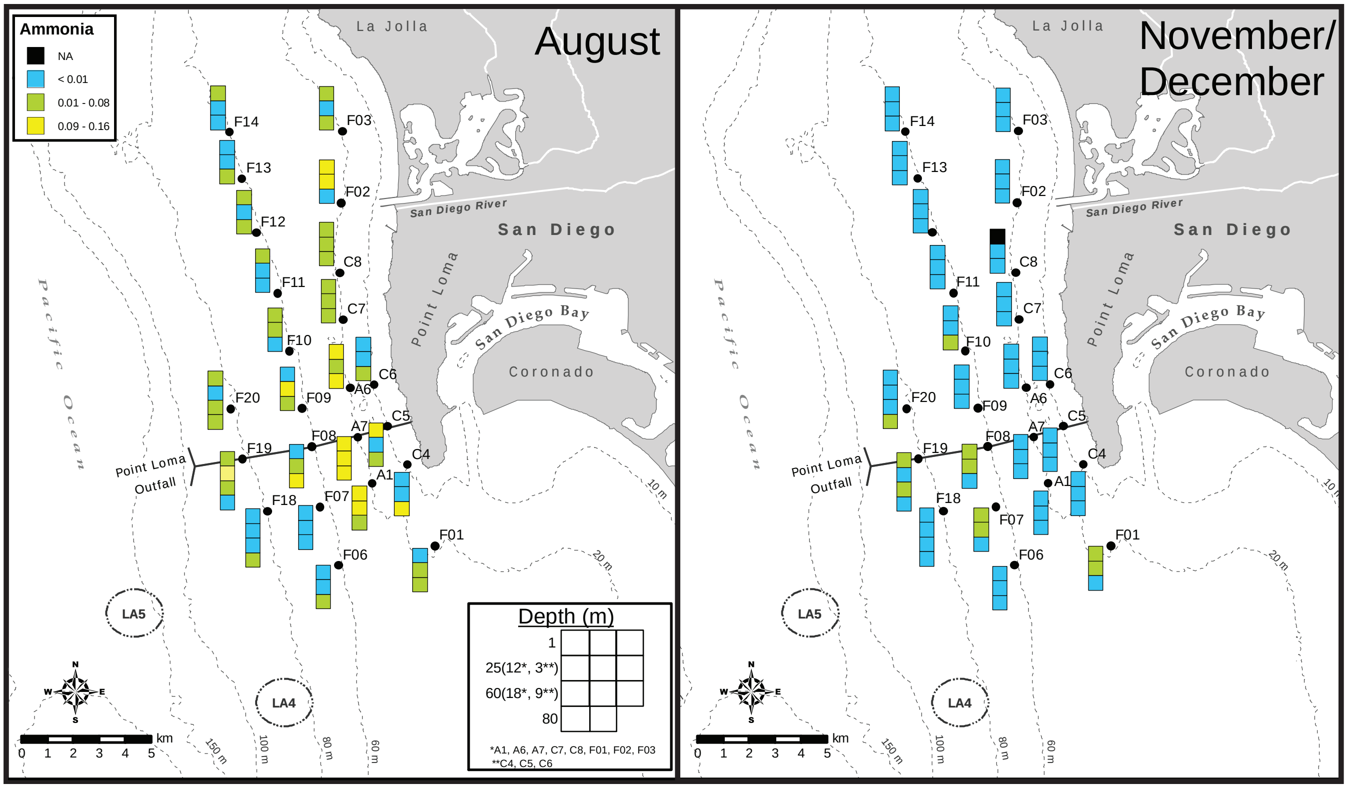


Figure 3.5

Distribution of ammonia (as nitrogen, mg/L) in seawater samples collected during the third and fourth PLOO quarterly surveys in 2010. NA=not analyzed. See text and Table 2.1 for sampling details.

City of San Diego. (2010a). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2009. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010b). Point Loma Ocean Outfall 2009 Annual Inspection Report. City of San Diego, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2011a). EMTS Division Laboratory Quality Assurance Report, 2010. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2011b). Monthly receiving waters monitoring report for the Point Loma Ocean Outfall – December 2010. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Grant, S., B. Sanders, A. Boehm, J. Redman, R. Kim, A. Chu, M. Gouldin, C. McGee, N. Gardiner, B. Jones, J. Svejkovsky, G. Leipzig. (2001). Generation of enterococci bacteria in a costal saltwater marsh and its impact on surf zone water quality. Environmental Science Technology, 35: 2407–2416.

Griffith, J., K. Schiff, G. Lyon, and J. Fuhrman. (2009). Microbiological water quality at non-human influenced reference beaches in southern California during wet weather. Marine Pollution Bulletin, 60: 500–508.

Gruber, S., L. Aumand, and A. Martin. (2005) Sediments as a reservoir of indicator bacteria in a coastal embayment: Mission Bay, California, Technical paper 0506. Westin Solutions, Inc. Presented at StormCon 2005. Orlando, FL, USA. July 2005.

Martin, A. and S. Gruber. (2005). Amplification of indicator bacteria in organic debris on southern California beaches. Technical Paper 0507. Weston Solutions, Inc. Presented at StormCon 2005. Orlando, FL, USA. July 2005.

Noble, R.T., D.F. Moore, M.K. Leecaster, C.D. McGee, S.B. Weisberg. (2003). Comparison of total coliform, fecal coliform, and enterococcus bacterial indicator response for ocean recreational water quality testing. Water Research. 37, 1637-1643.

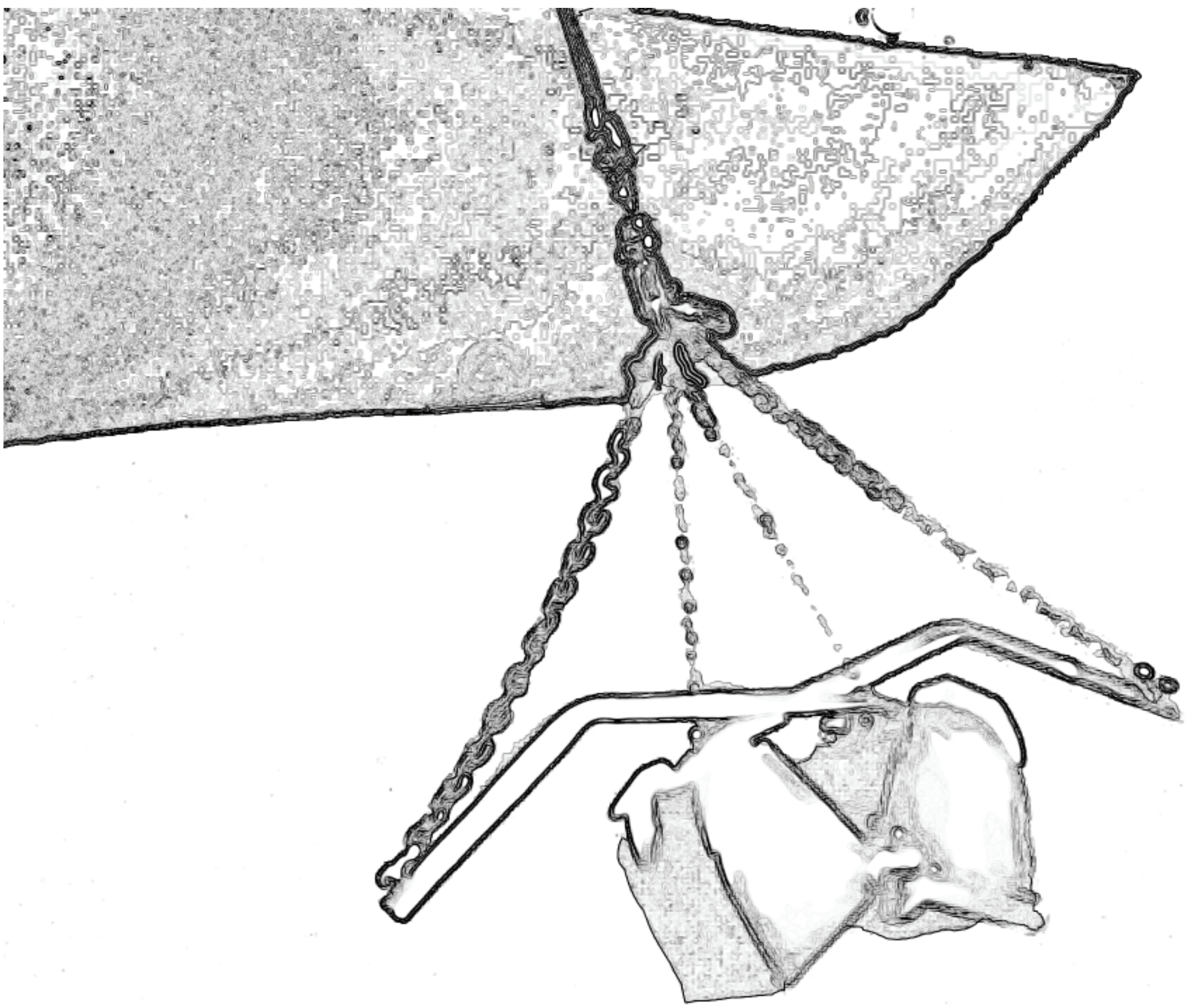
Ocean Imaging. (2011). Ocean Imaging Corporation archive of aerial and satellite-derived images. http://www.oceani.com/SanDiegoWater/index.html.

Svejkovsky, J. (2011). Satellite and Aerial Coastal Water Quality Monitoring in the San Diego/Tijuana Region: Annual Summary Report, 1 January, 2010–31 December, 2010. Ocean Imaging, Solana Beach, CA.

[SWRCB] California State Water Resources Control Board. (2001). California Ocean Plan, Water Quality Control Plan, Ocean Waters of California. California Environmental Protection Agency, Sacramento, CA.

[SWRCB] California State Water Resources Control Board. (2005). California Ocean Plan, Water Quality Control Plan, Ocean Waters of California. California Environmental Protection Agency, Sacramento, CA.

Chapter 4
Sediment Conditions



Chapter 4. Sediment Conditions

Introduction

Ocean sediment samples are collected and analyzed as part of the Point Loma Ocean Outfall (PLOO) monitoring program to characterize the general sediment quality in the region and to assess the potential impacts of wastewater discharge to the marine benthos. Analysis of parameters such as sediment particle size, sorting coefficients, and the relative percentages of coarse (e.g., gravel and sand) and fine (e.g., silt and clay) fractions provide useful information about current velocity, wave action, and overall habitat stability. Additionally, particle size composition can often be used to explain concentrations of chemical constituents within sediments since levels of organic compounds and trace metals generally rise with increasing amounts of fine particles (Emery 1960, Eganhouse and Venkatesan 1993). Finally, physical and chemical sediment characteristics are monitored because they define the primary microhabitats for benthic invertebrates that live within or on the seafloor, and subsequently influence the distribution and presence of various species. For example, differences in sediment composition and associated levels of organic loading affect the burrowing, tube building, and feeding abilities of infaunal invertebrates, thus affecting benthic community structure (Gray 1981, Snelgrove and Butman 1994). Also, many demersal fish species are associated with specific sediment types that reflect the habitats of their preferred invertebrate prey (Cross and Allen 1993). Overall, understanding the differences in sediment conditions and quality over time and space is crucial to assessing coincident changes in benthic invertebrate and demersal fish populations (see Chapters 5 and 6, respectively).

Both natural and anthropogenic factors affect the composition, distribution, and stability of seafloor sediments on the continental shelf. Natural factors that affect sediment conditions include geologic history, strength and direction of bottom currents, exposure to wave action, seafloor topography, inputs associated with outflows from rivers and bays, beach erosion, runoff from other terrestrial sources, bioturbation by fish and benthic invertebrates, and decomposition of calcareous organisms (Emery 1960). These processes affect the size and distribution of sediment types, and also sediment chemical composition. For example, erosion from coastal cliffs and shores, and flushing of terrestrial sediment and debris from bays, rivers, and streams augment the overall organic content and grain size of coastal sediments. These inputs can also contribute to the deposition and accumulation of trace metals or other contaminants to the sea floor. Primary productivity by marine phytoplankton and decomposition of marine and terrestrial organisms are also major sources of organic loading to coastal shelf sediments (Mann 1982, Parsons et al. 1990).

Municipal wastewater outfalls are one of many anthropogenic factors that can directly influence the composition and distribution of sediments through the discharge of treated effluent and the subsequent deposition of a wide variety of organic and inorganic compounds. Some of the most commonly detected contaminants discharged via ocean outfalls are trace metals, pesticides, and various organic compounds such as organic carbon, nitrogen, and sulfides (Anderson et al. 1993). In particular, organic enrichment by wastewater outfalls is of concern because it may impair habitat quality for benthic marine organisms and thus disrupt ecological processes. For example, sulfides, which are the byproducts of the anaerobic breakdown of organic matter, can be toxic to some benthic species if the sediments become excessively enriched (Gray 1981). Additionally, nitrogen enrichment can lead to sudden phytoplankton blooms in coastal waters, resulting in further organic loading (see above). Other contaminants originating from anthropogenic sources, such as trace metals and pesticides, may become incorporated into the tissues of organisms living near or within these marine sediments, and accumulate within the food web (see Chapter 7). Lastly, the physical presence of a large outfall pipe and associated ballast materials (e.g., rock, sand) may alter the hydrodynamic regime in surrounding areas, thus affecting sediment movement and transport, and the resident biological communities.

This chapter presents analyses and summaries of sediment particle size and chemistry data collected during 2010 at monitoring sites surrounding the PLOO. The primary goals of this chapter are to: (1) characterize the spatial and temporal variability of sediment parameters in order to assess possible effects of wastewater discharge on benthic habitats, (2) determine the presence or absence of sediment or contaminant deposition near the discharge site, and (3) evaluate overall sediment quality in the region.

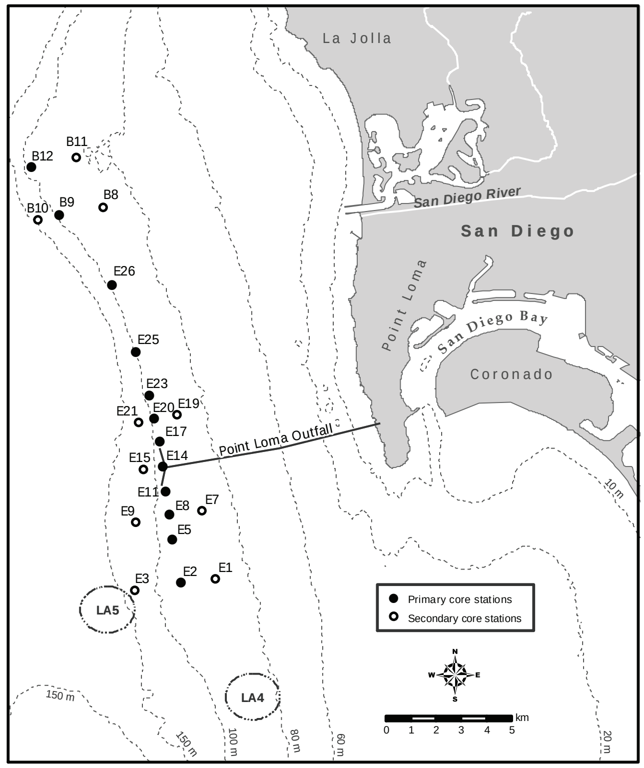


Figure 4.1
Benthic station locations sampled for the Point Loma Ocean Outfall Monitoring Program.

Materials and Methods

Field Sampling

Sediment samples were collected at 22 benthic stations in the PLOO region during January and July 2010 (Figure 4.1). These stations are located along the 88, 98, and 116-m depth contours, and include "E" stations located within 8 km of the outfall, and "B" stations located greater than 10 km from the outfall. The four stations considered to represent "nearfield" conditions herein (i.e., E11, E14, E15, E17) are located within 1000 m of the outfall wye. Each sediment sample was collected from one side of a chain-rigged double Van Veen grab with a 0.1-m^2 surface area; the other grab sample from the cast was used for macrofaunal community analysis (see Chapter 5) and visual observations of sediment composition. Sub-samples for various analyses were taken from the top 2 cm of the sediment surface and handled according to standard guidelines available in USEPA (1987).

Laboratory Analyses

All sediment chemistry and particle size analyses were performed at the City of San Diego's Wastewater Chemistry Services Laboratory. Particle size analysis was performed using either a Horiba LA-920 laser scattering particle analyzer or a set of six nested sieves. The Horiba analyzer measures particles ranging in size from 0.00049 to 2.0 mm (i.e., 11 to -1 phi). Coarser sediments from these samples were removed prior to laser analysis by screening the samples through a 2.0 mm mesh sieve. These data were later combined with the Horiba results to obtain a complete distribution of particle sizes totaling 100%. When a sample contained substantial amounts of coarse materials (e.g., coarse sand, gravel, shell hash) that would damage the Horiba analyzer and/or where the general distribution of sediment sizes would be poorly represented by laser analysis, a set of six nested sieves was instead used to separate the grain size fractions. The mesh sizes of the sieves are 2.0 mm, 1.0 mm, 0.5 mm, 0.25 mm, 0.125 mm, and 0.063 mm, and separate a seventh fraction of all particles finer than 0.063 mm. In 2010, 41 samples were processed by laser analysis and 3 samples (E3 in January, B11 and E14 in July) were processed by sieve analysis. Results from the sieve analysis and output from the Horiba were categorized into phi sizes based on the Wentworth scale (Appendix C.1). These phi sizes were then used in the calculation of various particle size parameters, which were determined using a normal probability scale (see Folk 1980). Summaries of particle size parameters included overall mean particle size (mm), phi size (mean, standard deviation, skewness, kurtosis), and the proportion of coarse, sand, silt, and clay. Additionally, the proportion of fine particles (percent fines) was calculated as the sum of all silt and clay fractions for each sample.

Each sediment sample was chemically analyzed to determine concentrations of total organic carbon (TOC), total nitrogen (TN), total sulfides, biochemical oxygen demand (BOD), total volatile solids (TVS), trace metals, chlorinated pesticides (e.g., DDT), polychlorinated biphenyl compounds (PCBs), and polycyclic aromatic hydrocarbons (PAHs) on a dry weight basis (see Appendix C.2). TOC, TN, and TVS were measured as percent weight (% wt) of the sediment sample; BOD, sulfides, and metals were measured in units of mg/kg and are expressed in this report as parts per million (ppm); pesticides and PCBs were measured in units of ng/kg and are expressed as parts per trillion (ppt); PAHs were measured in units of µg/kg and are expressed as parts per billion (ppb). Reported values were generally limited to values above the method detection limit (MDL) for each parameter. However, concentrations below MDLs were included as estimated values if the presence of the specific constituent was verified by mass-spectrometry. A more detailed description of the analytical protocols is provided by the Wastewater Chemical Services Laboratory (City of San Diego 2011).

Data Analyses

Data summaries for the various sediment parameters measured during 2010 included detection rates, annual means of detected values for all stations combined (areal mean), and minimum, median, and maximum values during the year. Total chlordane, total DDT (tDDT), total PCB (tPCB), and total PAH (tPAH) were calculated for each sample as the sum of all constituents with reported values (see Appendix C.3 for individual constituent values). Statistical analyses included Spearman rank correlation of percent fines with each chemical parameter. This non-parametric analysis accommodates non-detects (i.e., analyte concentrations measured below the MDL) without the use of value substitutions (Helsel 2005). However, depending on the data distribution, the instability in ranked-based analyses may intensify with increased censoring (Conover 1980). Therefore, a criterion of <50% non-detects was used to screen eligible constituents for this analysis. In addition, only parameters analyzed with a single MDL throughout the entire year were considered for correlation analysis (Helsel 2005). Correlation results were confirmed visually by graphical analyses.

Data from the 2010 surveys were compared to the Effects Range Low (ERL) and Effects Range Median (ERM) sediment quality guidelines of Long et al. (1995) when available to assess contamination levels. The National Status and Trends Program of the National Oceanic and Atmospheric Administration (NOAA) originally established the ERLs and ERMs to provide a means for interpreting environmental monitoring data. The ERLs represent chemical concentrations below which adverse biological effects are rarely observed. Values above the ERL but below the ERM represent values at which effects occasionally occur. Concentrations above the ERM indicate likely biological effects, although these are not always validated by toxicity testing (Schiff and Gossett 1998). Contamination levels were further evaluated by comparing results for the current year with historical data, including comparisons between the maximum values for 2010 to those from the pre-discharge period (i.e., 1991–1993).

RESULTS

Particle Size Distribution

During 2010, ocean sediments collected off Point Loma were composed predominantly of coarse

Table 4.1
Summary of particle size and sediment chemistry parameters at PLOO benthic stations during 2010. Data include the detection rate (DR), areal mean of detected values, and minimum, median, and maximum values for the entire survey area. The maximum value from the pre-discharge period (1991–1993) is also presented. ERL = Effects Range Low threshold; ERM = Effects Range Median threshold; SD = standard deviation.

	2010 Summary*					Pre-discharge		
Parameter	**DR (%)**	**Areal Mean**	**Min**	**Median**	**Max**	**Max**	**ERL**	**ERM**
Particle Size								
Mean (mm)	**	0.075	0.040	0.062	0.517	0.125	na	na
Mean (phi)	**	3.96	0.95	4.02	4.65	5.80	na	na
SD (phi)	**	1.57	1.34	1.51	2.41	3.00	na	na
Coarse (%)	**	2.3	0.0	0.0	52.9	26.4	na	na
Sand (%)	**	59.7	29.4	59.5	70.5	79.0	na	na
Fines (%)	**	38.0	15.9	38.5	58.3	74.2	na	na
Organic Indicators								
BOD (% weight)	100	346	156	335	980	656	na	na
Sulfides (ppm)	100	4.54	0.42	2.84	18.40	20.00	na	na
TN (% weight)	100	0.059	0.036	0.056	0.098	0.074	na	na
TOC (% weight)	100	0.900	0.360	0.646	4.810	1.24	na	na
TVS (% weight)	100	2.4	1.3	2.3	4.3	4.0	na	na
Trace Metals (*ppm*)								
Aluminum	100	7910	3450	7580	15,200	na	na	na
Antimony	41	0.47	nd	nd	1.20	6.0	na	na
Arsenic	100	2.92	0.78	2.71	6.11	5.56	8.2	70
Barium	100	40.30	15.30	37.00	69.40	na	na	na
Beryllium	48	0.16	nd	nd	0.33	2.01	na	na
Cadmium	93	0.15	nd	0.15	0.28	6.1	1.2	9.6
Chromium	100	17.2	7.0	15.5	32.9	43.6	81	370
Copper	100	8.78	3.75	8.19	16.30	34.0	34	270
Iron	100	12,140	4840	11,400	22,100	26,200	na	na
Lead	100	5.20	1.85	4.38	13.30	18.0	46.7	218
Manganese	100	87.9	37.6	82.5	152.0	na	na	na
Mercury	100	0.027	0.015	0.025	0.054	0.096	0.15	0.71
Nickel	100	7.16	3.30	6.96	10.60	14.0	20.9	51.6
Selenium	18	0.461	nd	nd	0.770	0.90	na	na
Silver	9	0.22	nd	nd	0.57	4.00	1	3.7
Thallium	0	—	nd	nd	nd	113.0	na	na
Tin	100	1.0	0.6	1.0	1.8	na	na	na
Zinc	100	30.5	13.3	29.6	45.3	67.0	150	410
Pesticides (*ppt*)								
HCH - Beta isomer	2	980	nd	nd	980	nd	na	na
HCB	14	159	nd	nd	220	nd	na	na
tDDT	93	640	nd	255	12,290	13,200	1580	46,100
Total PCB (*ppt*)	30	1676	nd	nd	7070	na	na	na
Total PAH (*ppb*)	11	100.1	nd	nd	294.4	199	4022	44,792

na = not available; nd = not detected

* Minimum, median, and maximum values were calculated based on all samples (*n* = 44), whereas means were calculated on detected values only (*n* ≤ 44).

** Particle size parameters calculated for all samples.

silt and sands, with mean particle sizes ranging from about 0.04 to 0.52 mm (Table 4.1). Overall, the fine fraction (i.e., silt and clay) averaged 38% during the year, ranging from a low of ~16% to a high of 58% (Figure 4.2). No major changes in percent fines composition of PLOO sediments have occurred since the initiation of wastewater discharge at the end of 1993 (Figure 4.3), with the exception of a slight decrease in fines and increase in mean particle size at nearfield station E14 (see City of San Diego 2007), a station that tends to demonstrate high particle size composition variability. For example, the percent fines fraction at E14 differed by more than 14% between the January and July 2010 surveys (Appendix C.4, Appendix C.5). Other examples of relatively large intra-station differences in particle size composition between surveys included station E3, where percent fines also differed by more than 14%, and station B11, where the coarse fraction increased from ~2% in January to ~26% in July.

The sorting coefficient is calculated as the standard deviation (SD) in phi size units for each sample, therefore reflecting the range of particle sizes present, and is considered indicative of the level of disturbance (e.g., fluctuating or variable currents and sediment deposition) in an area. Most stations sampled in the Point Loma region during 2010, including stations near the outfall, had poorly sorted sediments (i.e., sorting coefficients ranging from 1.3 to 1.9; Appendix C.4). The only exceptions to this pattern occurred at stations B11 and E14 in July, where sediments were very poorly sorted (SD = 2.4 and 2.1, respectively). These high sorting coefficients may be indicative of currents or sediment deposition that is more variable than at other PLOO stations. For example, visual observations of the sediments collected at E14 in July indicated relatively high amounts of coarse black sand and gravel, possibly related to ballast and bedding material deposited during the construction of the outfall in the early 1990s.

Indicators of Organic Loading

The distribution of organic indicators (i.e., TOC, TN, TVS, BOD, sulfides) in the region during

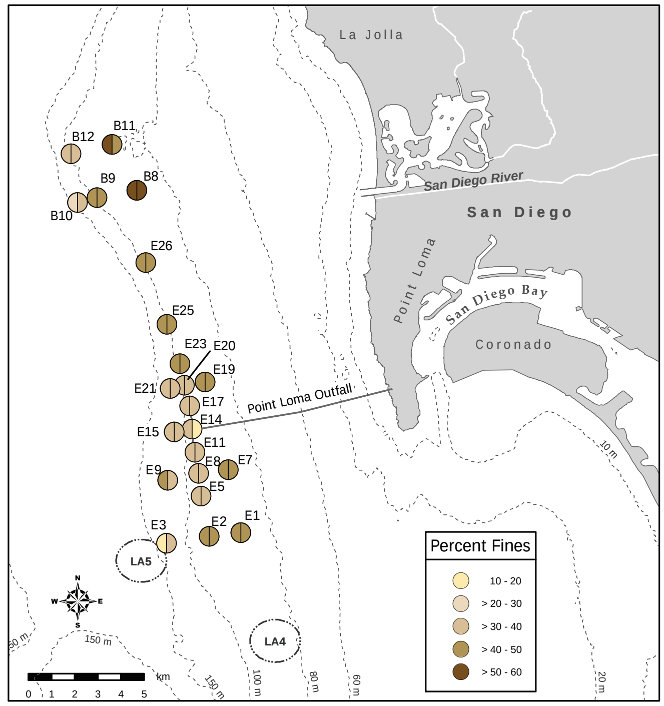


Figure 4.2
Distribution of fine sediments (percent fines) at PLOO benthic stations sampled during 2010. Split circles show results of January (left) and July (right) surveys.

2010 was generally similar to that seen prior to wastewater discharge (Figure 4.3; see also City of San Diego 1995). Each of these indicators was detected in 100% of the samples, and all but sulfides were detected at concentrations higher than the maximum values reported pre-discharge (Table 4.1). The highest concentrations of most organic indicators tended to occur at the northern "B" stations, located 10 km or more north of the outfall (Appendix C.6). The main exceptions to this pattern were values for sulfides, which were highest at station E17 in January, and BOD, which was highest at station E11 in July. In general, only sulfides, and to a lesser extent BOD, have shown changes near the outfall that appear to be associated with organic enrichment (City of San Diego 2007). Lastly, there was no correlation between sediment concentrations of organic indicators with the proportion of fine material within a sample (i.e., $r_s(44) < 0.7$).

Trace Metals

Detectable levels of aluminum, arsenic, barium, chromium, copper, iron, lead, manganese,

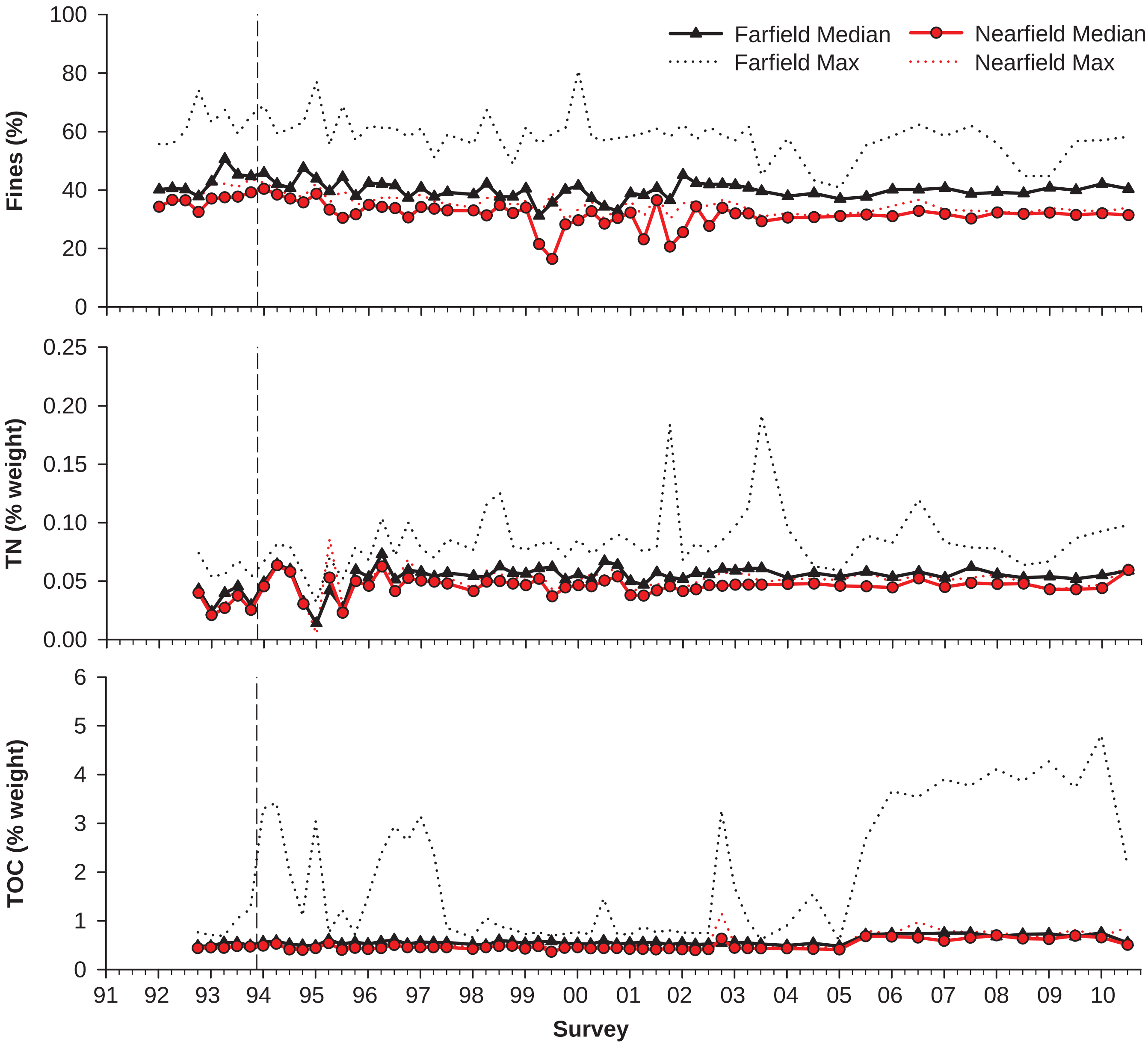


Figure 4.3
Percent fines (Fines) and organic indicator data from PLOO benthic stations sampled between 1991 and 2010. Data are expressed as median and maximum values of all farfield ($n = 18$) and nearfield ($n = 4$) samples during each survey; quarterly surveys were reduced to biannual (i.e., first and third quarters) in 2003; sampling was limited to primary core stations (farfield $n = 9$; nearfield $n = 3$) during the quarters 92-2, 03-3, 04-3, 05-1, 08-3, and 09-1 due to regulatory relief to accommodate special projects. Dashed lines indicate onset of discharge from the PLOO. Breaks in data represent surveys where the median or maximum value was below detection limits, not reportable, or not analyzed.

mercury, nickel, tin, and zinc occurred in all of the sediment samples collected in the Point Loma region during 2010 (Table 4.1). Another five metals (i.e., antimony, beryllium, cadmium, selenium, silver) were detected less frequently in 9–93% of samples, while thallium was not detected at all. Overall, concentrations of the different trace metals were low throughout the region, with most values reported for 2010 being below the maximum concentrations detected prior to wastewater discharge. Further, none of the sediment samples collected during 2010 contained metals at concentrations exceeding ERL or ERM thresholds. In addition to being low overall,

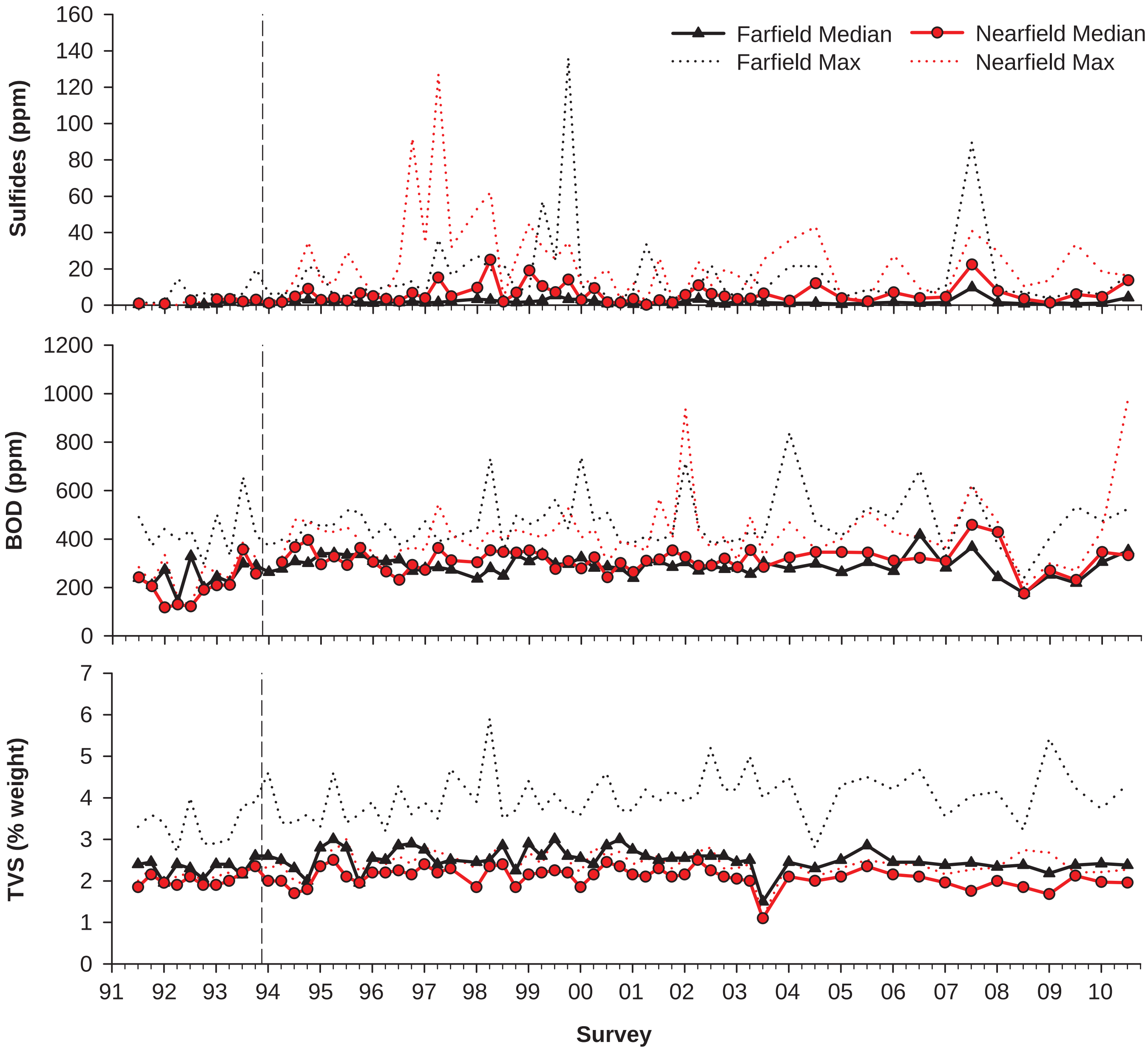


Figure 4.3 *continued*

metal concentrations were spatially variable, with no discernable patterns relative to the outfall (Appendix C.7) or with the proportion of fine material present in the sample (i.e., $r_s(44) < 0.7$). The highest concentrations of most metals occurred in sediments from the northern "B" stations, while the highest concentrations of a few others occurred at the "E" stations located south of the outfall. For example, the highest concentrations of barium and mercury were detected at stations E2 and E1 in January, respectively. In contrast, the maximum arsenic concentration detected in 2010 occurred in sediments collected at station E14 in July; this was the only instance during 2010 that a metal was found at higher concentrations than during the pre-discharge surveys.

Pesticides

Chlorinated pesticides were detected in up to 93% of the sediment samples collected from PLOO stations in 2010 (Table 4.1, Appendix C.8). Total DDT (primarily p,p-DDE) was the most prevalent pesticide, occurring at an overall mean concentration of 640 ppt. Concentrations of this pesticide exceeded the ERL (1580 ppt) in sediments from station E2 in January (1870 ppt) and B9 in July (12,290 ppt), both of which were below the maximum value of DDT reported for the region during the pre-discharge period (13,200 ppt). Another pesticide, HCB, was detected in 14% of the sediment samples at concentrations ranging from 76 to 220 ppt. HCB occurred at six sites throughout the region in January, including nearfield station E17, but was not detected in any samples in July. The maximum concentration of HCB was detected at station E5, located to the south of the outfall. A third pesticide, HCH (beta isomer), was detected at B11 in July at a concentration of 980 ppt. As with the organic indicators and most metals, no patterns indicative of an outfall effect were evident in the distribution of pesticides during 2010.

PCBs and PAHs

PCBs were detected in 30% of all PLOO sediment samples during 2010 (Table 4.1), most of which were collected from stations south of the outfall (Appendix C.8). Total PCB concentrations ranged from 53 to 7070 ppt in the region, with the maximum concentration occurring in sediment from station E21 in January. The most commonly detected PCB congeners were PCB 153/168, PCB 118, PCB 138, and PCB 149. Sediment from station E1 in January contained the most congeners (19) detected in a single sample. Overall, there was no evidence of PCB accumulation surrounding the PLOO.

PAHs also occurred infrequently in 2010, and were detected at only three sites, each located south of the outfall (i.e., stations E1, E2 and E3) (Appendix C.8). Total PAH concentrations ranged from about 20 to 294 ppb, well below the ERL of 4022 ppb (Table 4.1). The compounds 3,4 benzo(B)fluoranthene, benzo[A]anthracene, and benzo[A]pyrene occurred at all three of the above stations (Appendix C.2), while an additional five PAH compounds were also detected at station E1. Sediments collected from this station in January contained the highest tPAH concentration for the year. As with PCBs, there was no apparent relationship between PAH concentrations and proximity to the outfall discharge site.

Discussion

Ocean sediments at stations surrounding the PLOO in 2010 were composed primarily of sands and coarse silt. Most of these sediments were poorly sorted, consisting of particles of varied sizes, which suggest that sediments in the region were subject to low wave and current activity and/or variable physical disturbance (Folk 1980). The very poorly sorted samples collected at stations B11 and E14 in July were exceptions, containing substantially more gravel and very coarse sands, and less fine sands and silt than most other stations in the region. The sample from station E14 in particular consisted of over 50% coarse particles, which may have originated as ballast or bedding material for the outfall structure. Overall, variability in the particle size composition of sediments in the PLOO region is likely affected by both anthropogenic and natural influences, including outfall construction materials, offshore disposal of dredged materials, multiple geologic origins of different sediment types, and recent deposition of sediment and detrital materials (Emery 1960, City of San Diego 2007, Parnell et al. 2008). The PLOO lies within the Mission Bay littoral cell, with natural sources of sediments including outflows from Mission Bay, the San Diego River (Patsch and Griggs 2007), as well as San Diego Bay. However, fine particles may also travel in suspension across littoral cell borders up and down the coast (Farnsworth and Warrick 2007), thus widening the range of potential sediment sources to the region.

Concentrations of various contaminants, including indicators of organic loading (i.e., BOD, TOC, TN, sulfides, TVS), trace metals, chlorinated pesticides (e.g., DDT), PCBs, and PAHs in sediments off Point Loma remained within the typical range observed for San Diego and other areas of the southern California continental shelf (see Schiff and Gossett 1998, Noblet et al. 2003, Schiff et al. 2006, Maruya and Schiff 2009). Although DDT was detected above the ERL for this pesticide at two stations, these concentrations were below the maximum value detected in the region pre-discharge.

There were no clear spatial patterns in sediment contaminants relative to the PLOO discharge site in 2010, with the exception of slightly elevated sulfide and BOD levels near the outfall as described in previous years (City of San Diego 2007). Instead, the highest concentrations of several organic indicators, metals, pesticides, PCBs, and PAHs were found in sediments from the southern- and/or northern-most farfield stations. Historically, concentrations of contaminants have been higher in sediments at southern stations (i.e., E1–E3, E5, E7–E9) than elsewhere off San Diego, which may be due in part to short dumps of dredged materials destined originally for LA-5 (Anderson et al. 1993, City of San Diego 2003, Steinberger et al. 2003, Parnell et al. 2008).

Overall, there is little evidence of contaminant loading or organic enrichment in sediments throughout the PLOO region after 17 years of wastewater discharge. For example, concentrations of most measured parameters continue to occur at levels within the range of variability typical for the San Diego region (e.g., see City of San Diego 2007). The only sustained effects have been restricted to a few sites located within about 300 m of the outfall (i.e., stations E11, E14 and E17). These effects include a minor increase in sediment particle size through time, measurable increases in sulfide concentrations, and smaller increases in BOD (City of San Diego 2007). However, the data do not suggest that wastewater discharge is affecting the quality of benthic sediments to the point that it will degrade the resident marine biota in the PLOO region (e.g., see Chapters 5 and 6).

Literature Cited

Anderson, J.W., D.J. Reish, R.B. Spies, M.E. Brady, and E.W. Segelhorst. (1993). Human Impacts. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. p 682–766.

City of San Diego. (1995). Outfall Extension Pre-Construction Monitoring Report (July 1991–October 1992). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2003). An Ecological Assessment of San Diego Bay: A Component of the Bight'98 Regional Survey. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2007). Appendix E. Benthic Sediments and Organisms. In: Application for Renewal of NPDES CA0107409 and 301(h) Modified Secondary Treatment Requirements Point Loma Ocean Outfall. Volume IV, Appendices A thru F. Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2011). 2010 Annual Reports and Summary: Point Loma Wastewater Treatment Plant and Point Loma Ocean Outfall. City of San Diego, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Conover, W.J. (1980). Practical Nonparametric Statistics, 2ed. John Wiley & Sons, Inc., New York, NY.

Cross, J.N. and L.G. Allen. (1993). Fishes. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. p 459–540.

Eganhouse, R.P. and M.I. Venkatesan. (1993). Chemical Oceanography and Geochemistry. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. p 71–189.

Emery, K.O. (1960). The Sea off Southern California. John Wiley, New York, NY.

Farnsworth, K.L. and J.A. Warrick. (2007). Sources, dispersal, and fate of fine sediment supplied to coastal California. U.S. Geological Survey Scientific Investigations Report 2007–5254. Reston, VA.

Folk, R.L. (1980). Petrology of Sedimentary Rocks. Hemphill, Austin, TX.

Gray, J.S. (1981). The Ecology of Marine Sediments: An Introduction to the Structure and Function of Benthic Communities. Cambridge University Press, Cambridge, England.

Helsel, D.R. (2005). Nondetects and Data Analysis: Statistics for Censored Environmental Data. John Wiley & Sons, Inc., Hoboken, NJ.

Long, E.R., D.L. MacDonald, S.L. Smith, and F.D. Calder. (1995). Incidence of adverse biological effects within ranges of chemical concentration in marine and estuarine sediments. Environmental Management, 19(1): 81–97.

Mann, K.H. (1982). The Ecology of Coastal Marine Waters: A Systems Approach. University of California Press, Berkeley, CA.

Maruya, K.A. and K. Schiff. (2009). The extent and magnitude of sediment contamination in the Southern California Bight. Geological Society of America Special Paper, 454: 399–412.

Noblet, J.A., E.Y. Zeng, R. Baird, R.W. Gossett, R.J. Ozretich, and C.R. Phillips. (2003). Southern California Bight 1998 Regional Monitoring Program: VI. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

Parnell, P.E., A.K. Groce, T.D. Stebbins, and P.K. Dayton. (2008). Discriminating sources of PCB contamination in fish on the coastal shelf off San Diego, California (USA). Marine Pollution Bulletin, 56: 1992–2002.

Parsons, T.R., M. Takahashi, and B. Hargrave (1990). Biological Oceanographic Processes 3rd Edition. Pergamon Press, Oxford.

Patsch, K. and G. Griggs. (2007). Development of Sand Budgets for California's Major Littoral Cells. Institute of Marine Sciences, University of California, Santa Cruz, CA.

Schiff, K.C. and R.W. Gossett. (1998). Southern California Bight 1994 Pilot Project: III. Sediment Chemistry. Southern California Coastal Water Research Project. Westminster, CA.

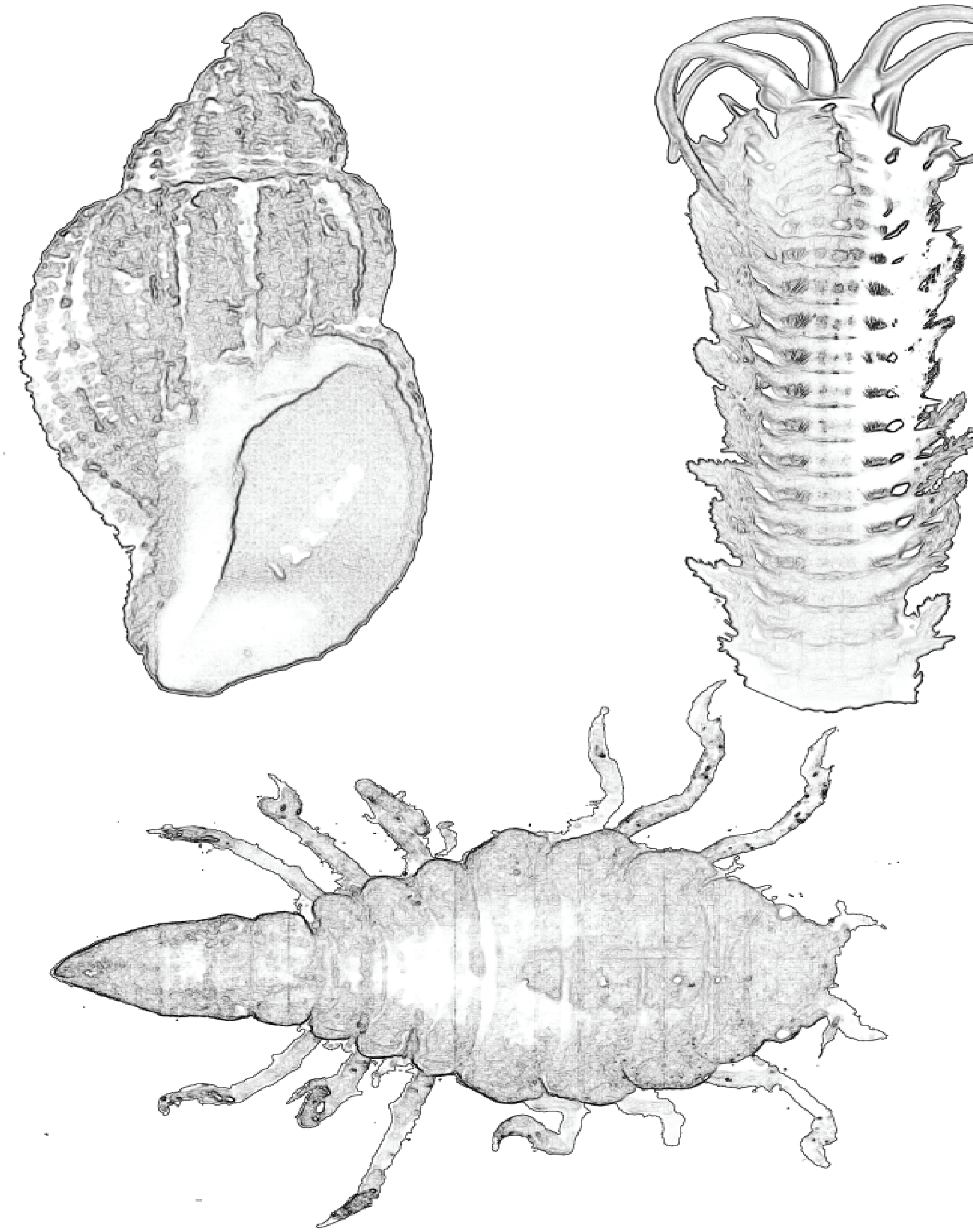
Schiff, K., K. Maruya, and K. Christenson. (2006). Southern California Bight 2003 Regional Monitoring Program: II. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

Snelgrove, P.V.R. and C.A. Butman. (1994). Animal-sediment relationships revisited: cause versus effect. Oceanography and Marine Biology Annual Review, 32: 111–177.

Steinberger, A., E. Stein, and K. Schiff. (2003). Characteristics of dredged material disposal to the Southern California Bight between 1991 and 1997. In: Southern California Coastal Water Research Project Biennial Report 2001–2002. Long Beach, CA. p 50–60.

[USEPA] United States Environmental Protection Agency. (1987). Quality Assurance and Quality Control for 301(h) Monitoring Programs: Guidance on Field and Laboratory Methods. EPA Document 430/9-86-004. Office of Marine and Estuary Protection, Washington, DC.

Chapter 5
Macrobenthic Communities



Chapter 5. Macrobenthic Communities

Introduction

Benthic macroinvertebrates along the coastal shelf of southern California represent a diverse faunal community that is important to the marine ecosystem (Fauchald and Jones 1979, Thompson et al. 1993a, Bergen et al. 2001). These animals serve vital ecological functions in wide ranging capacities (Snelgrove et al. 1997). For example, some species decompose organic material as a crucial step in nutrient cycling; other species filter suspended particles from the water column, thus affecting water clarity. Many species of benthic macrofauna also are essential prey for fish and other organisms.

Human activities that impact the benthos can sometimes result in toxic contamination, oxygen depletion, nutrient loading, or other forms of environmental degradation. Certain macrofaunal species are sensitive to such changes and rarely occur in impacted areas, while others are opportunistic and can persist under altered conditions (Gray 1979). Because various species respond differently to environmental stress, monitoring macrobenthic assemblages can help to identify anthropogenic impact (Pearson and Rosenberg 1978, Bilyard 1987, Warwick and Clarke 1993, Smith et al. 2001). Also, since many animals in these assemblages are relatively stationary and long-lived, they can integrate the effects of local environmental stressors (e.g., pollution or disturbance) over time (Hartley 1982, Bilyard 1987). Consequently, the assessment of benthic community structure is a major component of many marine monitoring programs, which are often designed to document both existing conditions and trends over time.

Overall, the structure of benthic communities may be influenced by many factors including depth, sediment composition and quality (e.g., grain size distribution, contaminant concentrations), oceanographic conditions (e.g., temperature, salinity, dissolved oxygen, ocean currents), and biological factors (e.g., food availability, competition, predation). For example, benthic assemblages on the coastal shelf of southern California typically vary along sediment particle size and/or depth gradients (Bergen et al. 2001). Therefore, in order to determine whether changes in community structure are related to human impacts, it is necessary to have an understanding of background or reference conditions for an area. Such information is available for the monitoring area surrounding the Point Loma Ocean Outfall (PLOO) and the San Diego region in general (e.g., see City of San Diego 1999, 2010, Ranasinghe et al. 2003, 2007).

This chapter presents analyses and interpretations of the macrofaunal data collected in 2010 at fixed stations surrounding the PLOO, including comparisons of the different soft-bottom macrofaunal assemblages in the region and descriptions of benthic community structure. The primary goals are to: (1) identify possible effects of wastewater discharge on local macrofaunal communities, (2) determine the presence or absence of biological impacts near the discharge site, and (3) identify any spatial or temporal trends in benthic community structure in the region.

Materials and Methods

Collection and Processing of Samples

Benthic samples were collected at 22 benthic stations in the PLOO region located along the 88, 98, or 116-m depth contours (Figure 5.1). These sites included 17 “E” stations located from approximately 5 km south to 8 km north of the outfall, and five “B” stations located at least 10 km north of the outfall. Four of these stations are considered to represent “nearfield” conditions (i.e., E11, E14, E15, E17) and are located within 1000 m of the outfall wye or diffuser legs.

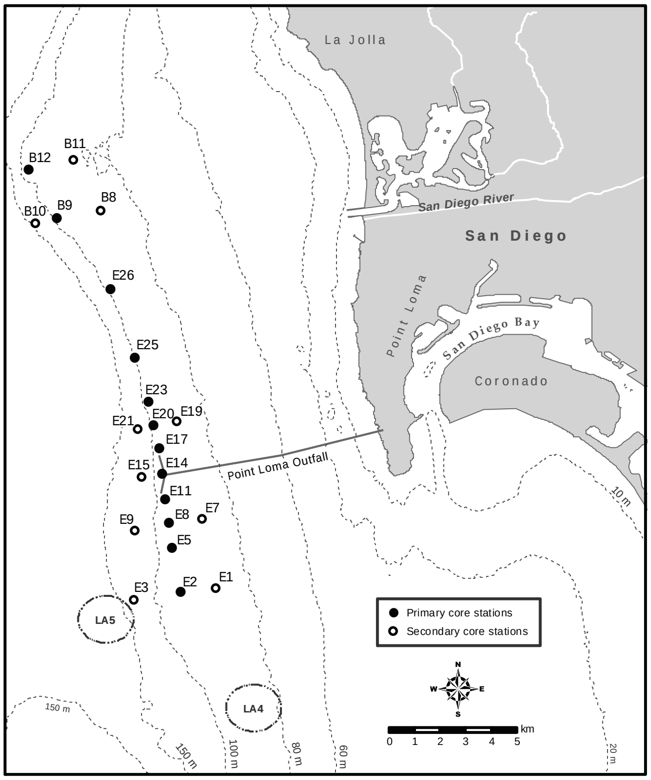


Figure 5.1
Benthic station locations sampled for the Point Loma Ocean Outfall Monitoring Program.

Two replicate samples for benthic community analyses were collected per station during each survey using a double 0.1-m^2 Van Veen grab. One of the two grabs from the first cast was used for analysis of macrofauna, while the adjacent grab was used for sediment quality analysis (see Chapter 4); a second grab for macrofauna was then collected from a subsequent cast. Criteria established by the USEPA to ensure consistency of grab samples were followed with regard to sample disturbance and depth of penetration (USEPA 1987). All samples were sieved aboard ship through a 1.0-mm mesh screen. Organisms retained on the screen were collected and relaxed for 30 minutes in a magnesium sulfate solution and then fixed in buffered formalin. After a minimum of 72 hours, each sample was rinsed with fresh water and transferred to 70% ethanol. All animals were sorted from the debris into major taxonomic groups by a subcontractor, and then identified to species (or the lowest taxon possible) and enumerated by City of San Diego marine biologists.

Data Analyses

The following community structure parameters were calculated for each station per 0.1-m^2 grab: species richness (number of species), abundance (number of individuals), Shannon diversity index (H'), Pielou's evenness index (J'), Swartz dominance (see Swartz et al. 1986, Ferraro et al. 1994), and benthic response index (BRI; see Smith et al. 2001). Additionally, the total or cumulative number of species over all grabs was calculated for each station.

In order to examine spatial and temporal patterns among benthic macroinvertebrate communities in the PLOO region, multivariate analyses were conducted using PRIMER (Clarke and Warwick 2001, Clarke and Gorley 2006). Data from each Van Veen grab were considered individual replicates, and a square-root transformation was performed on the resultant abundance data matrix to lessen the influence of prevalent species and increase the weight of rare species. A Bray-Curtis similarity matrix was created from transformed data, with site provided as a factor. One-way analysis of similarity (ANOSIM, maximum number of permutations = 9999) was conducted to determine whether benthic macroinvertebrate communities varied spatially across the PLOO region. To visually depict the relationship of all individual grab samples to each other based on benthic invertebrate composition, a cluster dendrogram was created, and similarity profile (SIMPROF) analysis was used to confirm non-random structure of the resultant clades (Clarke et al. 2008). Similarity percentages (SIMPER) analysis was used to identify which species accounted for differences between clades occurring in the dendrogram.

A BACIP (Before-After-Control-Impact-Paired) statistical model was used to test the null hypothesis that there have been no changes in select community parameters due to operation of the PLOO (Bernstein and Zalinski 1983, Stewart-Oaten et al. 1986, 1992, Osenberg et al. 1994). The BACIP model compares differences between control (reference) and impact sites at times before

(July 1991–October 1993) and after (January 1994–July 2010) an impact event (i.e., the onset of discharge). The analyses presented in this report are based on 2.5 years (10 quarterly surveys) of before impact data and 17 years (53 quarterly or semi-annual surveys) of after impact data. The E stations, located between ~0.1 and 8 km of the outfall, are considered most likely to be affected by wastewater discharge (Smith and Riege 1994). Station E14 was selected as the impact site for all analyses; this station is located near the boundary of the Zone of Initial Dilution (ZID) and probably is the site most susceptible to impact. The B stations are located farther from the outfall (>10 km) and are the obvious candidates for reference or control sites. However, benthic communities differed between the B and E stations prior to discharge (Smith and Riege 1994, City of San Diego 1995). Thus, two stations (E26 and B9) were selected to represent separate control sites in the BACIP tests. Station E26 is located 8 km north of the outfall and is considered the E station least likely to be impacted. Previous analyses suggested that station B9 was one of the most appropriate B stations for comparison with the E stations (Smith and Riege 1994, City of San Diego 1995). Six dependent variables were analyzed, including three community parameters (number of species, infaunal abundance, BRI) and abundances of three taxa that are considered sensitive to organic enrichment. These indicator taxa include ophiuroids in the genus *Amphiodia* (mostly *A. urtica*), and amphipods in the genera *Ampelisca* and *Rhepoxynius*. All BACIP analyses were interpreted using one-tailed paired t-tests with a type I error rate of $\alpha = 0.05$.

Results

Community Parameters

Species richness

A total of 564 taxa were identified during the 2010 PLOO surveys. Of these, 445 taxa were identified to the species level, 63 to genus, 33 to family, 11 to order, 10 to class, and 2 individuals to phylum. The majority of taxa were found throughout the region, while about 26% ($n = 146$) represented taxa that were recorded only once. Annual mean values of species richness ranged from a low of 71 taxa per 0.1 m^2 at station E1 to a high of 120 taxa per 0.1 m^2 at station E14 (Table 5.1). Overall, the average species richness among the 12 primary core stations increased ~3% since 2009. This comparison between years is limited to the 12 primary core stations because of a reduction in sampling during January 2009 to accommodate the Bight'08 regional project (City of San Diego 2010).

Macrofaunal abundance

A total of 27,684 macrofaunal individuals were counted in 2010, with mean abundance values ranging from 245 to 491 animals per 0.1 m^2 (Table 5.1). The greatest number of animals occurred at nearfield station E14, which averaged 491 individuals per sample. In contrast, the fewest animals occurred at station E3 (245/0.1 m^2) located near the LA-5 disposal site. Overall, there was a ~3% increase in macrofaunal abundance collected at the 12 primary core stations between 2009 and 2010, with the largest increase occurring at station E14 (City of San Diego 2010).

Species diversity, evenness, and dominance

Diversity index values (H') averaged from 3.1 to 4.2 at PLOO stations during 2010 (Table 5.1), and were similar to values for previous years (e.g., City of San Diego 1995, 2010). The lowest diversity (H' = 3.1) occurred at station E1, while the remaining stations had mean H' values ≥ 3.4. There were no apparent patterns in diversity relative to distance from the discharge site (Table 5.1). Evenness (J') compliments diversity, with higher J' values (on a scale of 0–1) indicating that species are more evenly distributed and the assemblage is not dominated by a few highly abundant species. During 2010, J' values averaged between 0.72 and 0.92 per station, with spatial patterns similar to those for diversity. Benthic assemblages in 2010 were characterized by relatively high numbers of evenly distributed species during the year. Swartz dominance values averaged from 21 to 45 species per station with the highest value occurring at

Table 5.1

Summary of macrofaunal community parameters for PLOO benthic stations sampled during 2010. Tot Spp = cumulative number of species for the year; SR = species richness (no. species/0.1 m^2); Abun = abundance (no. individuals/0.1 m^2); H' = Shannon diversity index; J' = evenness; Dom = Swartz dominance; BRI = benthic response index; * = nearfield stations. Data are expressed as annual means ($n = 4$) except Tot Spp ($n = 1$).

	Station	Tot Spp	SR	Abun	H'	J'	Dom	BRI
88-m Depth Contour	B11	252	118	331	4.2	0.88	45	9
	B8	156	76	263	3.4	0.79	23	3
	E19	174	92	328	3.9	0.86	32	8
	E7	164	90	321	3.8	0.85	32	6
	E1	152	71	251	3.1	0.72	21	4
98-m Depth Contour	B12	202	102	321	4.1	0.88	36	10
	B9	157	81	274	3.9	0.89	31	7
	E26	157	84	314	3.8	0.87	30	10
	E25	164	90	375	3.9	0.86	29	8
	E23	170	89	289	4.0	0.89	33	10
	E20	169	88	326	3.9	0.87	30	10
	E17*	162	86	334	3.9	0.87	29	14
	E14*	259	120	491	4.1	0.86	37	20
	E11*	155	81	303	3.8	0.86	27	15
	E8	171	90	283	4.0	0.89	34	10
	E5	183	97	311	4.1	0.90	38	9
	E2	168	86	281	3.8	0.86	32	7
116-m Depth Contour	B10	197	101	353	4.0	0.87	36	13
	E21	166	83	248	4.0	0.90	32	10
	E15*	195	100	380	4.1	0.89	37	9
	E9	193	97	300	4.1	0.89	40	7
	E3	195	100	245	4.2	0.92	43	7
All Grabs	Mean	180	92	315	3.9	0.87	33	9
	Std Error	6	2	7	0.1	0.01	1	0.4
	Min	152	56	140	3.0	0.70	19	2
	Max	259	129	570	4.4	0.94	50	26

station B11, one of the northern reference stations (Table 5.1). The lowest dominance value occurred at station E1 located inshore of the LA-5 disposal site. Overall, the results for 2010 were similar to historical values for the PLOO region (see City of San Diego 2007).

Benthic response index

The benthic response index (BRI) is a useful tool for evaluating environmental conditions in soft-bottom benthic habitats off southern California at depths between 10–324 m (Smith et al. 2001). BRI values < 25 are considered indicative of reference conditions, while values between 25–34 represent a minor or marginal deviation from reference conditions. Higher BRI values > 34 represent progressive levels of impact from losses in biodiversity, community function, and ultimately defaunation. About 99% of the benthic samples collected off Point Loma in 2010 had BRI values < 25 and were therefore indicative of reference conditions. Overall, BRI values averaged from 3 to 20 at the different stations, while individual grab sample values ranged from 2 to 26 (Table 5.1).

The single sample with the relatively high BRI of 26 occurred at near-ZID station E14, which also had the highest annual mean BRI of 20. The three next highest mean BRI values of 13–15 occurred at nearfield stations E11 and E17 and northern reference station B10. BRI values at all other stations averaged ≤10 during the year, with the lowest BRI value of 3 occurring at reference station B8.

Dominant Species

In 2010, macrofaunal diversity in the PLOO region was dominated by polychaete worms, which accounted for 55% of all species collected (Table 5.2). Crustaceans accounted for 24% of species reported, while molluscs, echinoderms, and all other taxa combined accounted for the remaining 11%, 5%, and 5%, respectively. Polychaetes were also the most numerous animals, accounting for 57% of the total abundance. Crustaceans accounted for 20% of the animals collected, molluscs 10%, echinoderms 11%, and the remaining phyla 2%. Overall, the percentage of taxa that fell within each major taxonomic grouping and their relative abundances were similar to those observed in 2009 (City of San Diego 2010).

The 10 most abundant macroinvertebrates sampled during the year included six polychaetes, two crustaceans, one echinoderm and one mollusc (Table 5.3). The numerically dominant polychaetes were the terebellid *Polycirrus* sp A, the paraonid *Aricidea* (*Acmira*) *catherinae*, the cirratulids *Chaetozone hartmanae* and *Aphelochaeta glandaria* complex, the capitellid *Mediomastus* sp, and the ampharetid *Lysippe* sp A. The two dominant crustaceans were the ostracods *Euphilomedes producta* and *E. carcharodonta*. The dominant echinoderm and mollusc were the ophiuroid *Amphiodia urtica* and the bivalve *Axinopsida*

Table 5.2
Percent composition of species and abundance by major taxonomic group (phylum) for PLOO stations sampled during 2010. Data are expressed as annual means (range) for all stations combined; *n* = 22.

Phyla	Species (%)	Abundance (%)
Annelida (Polychaeta)	55 (46–61)	57 (32–73)
Arthropoda (Crustacea)	24 (18–29)	20 (9–29)
Mollusca	11 (7–15)	10 (3–25)
Echinodermata	5 (3–8)	11 (2–42)
Other Phyla	5 (2–8)	2 (1–4)

Table 5.3
The 10 most abundant macroinvertebrates collected at the PLOO benthic stations sampled during 2010. Abundance values are expressed as mean number of individuals per 0.1-m^2 grab sample. Percent occurrence = percent of total annual samples where the species was collected.

Species	Higher Taxa	Abundance per Sample	Percent Occurrence
Amphiodia urtica	Echinodermata: Ophiuroidea	25.5	98
Axinopsida serricata	Mollusca: Bivalvia	10.8	89
Euphilomedes producta	Arthropoda: Ostracoda	9.9	91
Polycirrus sp A	Polychaeta: Terebellidae	9.6	95
Aricidea (*Acmira*) *catherinae*	Polychaeta: Paraonidae	8.1	95
Chaetozone hartmanae	Polychaeta: Cirratulidae	7.2	98
Mediomastus sp	Polychaeta: Capitellidae	6.6	95
Aphelochaeta glandaria Cmplx	Polychaeta: Cirratulidae	6.3	93
Euphilomedes carcharodonta	Arthropoda: Ostracoda	5.7	86
Lysippe sp A	Polychaeta: Ampharetidae	5.1	100

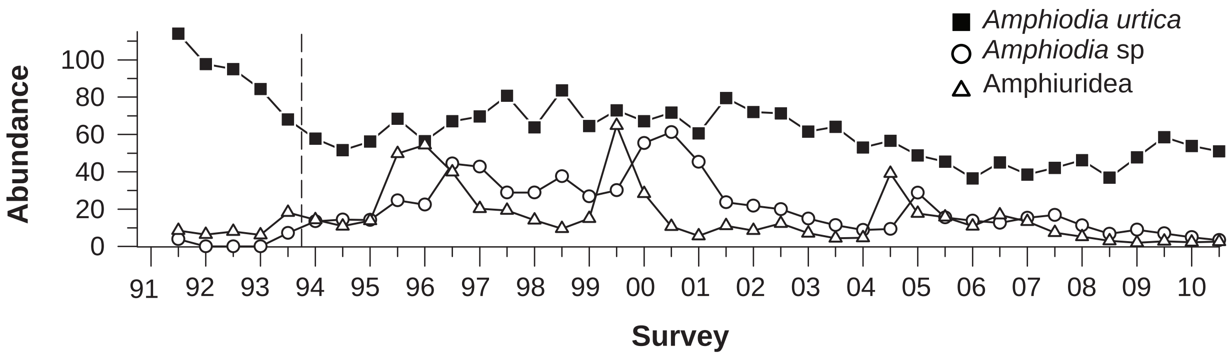


Figure 5.2

Abundance per survey for adult *Amphiodia urtica* and unidentifiable juveniles (*Amphiodia* sp and Amphiuridea) from PLOO benthic stations sampled between 1991 and 2010. Data are expressed as mean values of biannual (i.e., first and third quarters) samples during each survey ($n=22$); sampling was limited to primary core stations ($n=12$) during the quarters 03-3, 04-3, 05-1, 08-3, and 09-1 due to regulatory relief to accommodate special projects. Dashed line indicates onset of discharge from the PLOO.

serricata, respectively. The most abundant species collected overall was the ophiuroid *Amphiodia urtica*, which occurred at 98% of stations surveyed and averaged ~26 individuals per sample. While *A. urtica* was nearly ubiquitous in the PLOO region, abundances at individual stations varied (range 7–383 individuals/site). Overall, *A. urtica* accounted for ~8% of the macrobenthic fauna sampled during 2010 and has been among the most abundant species collected since monitoring began in 1991 (Figure 5.2).

Many of the dominant species collected in 2010 figured prominently in past years as well. For example, five of the most abundant species collected in 2010 (i.e., *Amphiodia urtica*, *Euphilomedes producta, E. carcharodonta*, *Chaetozone hartmanae*, *Mediomastus* sp) were among the 10 most abundant taxa collected historically (Appendix D.1). In contrast, some species were found in relatively high abundances at a limited number of stations. For example, the gastropod mollusc *Micranellum crebricinctum* was collected at only two stations (B12 and E3), but with mean abundances of 8.5 animals per 0.1 m^2 grab.

BACIP Analyses

BACIP t-tests indicate that there has been a net change in the mean difference of species richness, BRI values, and *Amphiodia* spp abundance between impact site E14 and both control sites since the onset of wastewater discharge from the PLOO (Table 5.4). There also has been a net change in infaunal abundance between E14 and control site B9, and a net change in *Ampelisca* spp abundance between E14 and E26. The change in species richness is likely driven by increased variability and higher numbers of species at E14 between 1997 and 2007 (Figure 5.3A). Differences in *Amphiodia* populations reflect both a decrease in the number of ophiuroids collected at E14 and a general increase at the control stations until about 2006 (Figure 5.3E). *Amphiodia urtica* densities at station E14 in 2010 are in range of the low densities that have been reported since about 1999. While populations of this brittle star have declined in recent years at both control sites, their densities at these sites are more similar to pre-discharge values than near the outfall. Changes in BRI differences generally have occurred due to increased index values at station E14 since 1994 (Figure 5.3C). The BACIP results for total infaunal abundances were more ambiguous (Figure 5.3B, Table 5.4). While the difference in mean abundances between stations B9 and E14 has changed since discharge began, no significant change is apparent regarding the second control site (station E26). No significant changes in the difference in mean abundances of phoxocephalid amphipods (i.e., *Rhepoxynius*) at the impact and control sites have occurred over time (Table 5.4). However, there has been a significant change in the difference in mean abundance of ampeliscid

Table 5.4

Results of BACIP t-tests for species richness (SR), infaunal abundance, BRI, and abundance of several representative taxa around the PLOO (1991–2010). Critical t-value = 1.680 for $\alpha = 0.05$ (one-tailed t-tests, df = 61); ns = not significant.

Variable	Control vs. Impact	t	*p*
SR	E26 vs E14	-3.17	0.001
	B9 vs E14	-3.52	< 0.001
Abundance	E26 vs E14	-1.46	ns
	B9 vs E14	-2.78	0.004
BRI	E26 vs E14	-15.53	< 0.001
	B9 vs E14	-10.72	< 0.001
Ampelisca spp	E26 vs E14	-1.95	0.028
	B9 vs E14	-1.31	ns
Amphiodia spp	E26 vs E14	-6.50	< 0.001
	B9 vs E14	-4.51	< 0.001
Rhepoxynius spp	E26 vs E14	-0.61	ns
	B9 vs E14	-0.53	ns

amphipods (i.e., *Ampelisca*) between E14 and E26 (Figure 5.3D, Table 5.4).

Classification of Macrobenthic Assemblages

ANOSIM results revealed that benthic invertebrate communities differed significantly between most sites (Global R = 0.705, $p = 0.0001$), although several pairwise comparisons between individual sites immediately north and south of the PLOO were non-significant (i.e., E20, E21, E23, E25 and E5, E8, E11). Station E14, located nearest the PLOO, as well as all 88-m sites, all 116-m sites, and the extreme northern and southern 98-m sites (Figure 5.1) contained invertebrate communities that were significantly different from every other site.

Cluster analysis examined the relationship of invertebrate communities from each individual Van Veen grab (two grabs over each sampling period). In accordance with some of the statistical similarities revealed through ANOSIM, the cluster analysis revealed a large clade comprising 47 samples that shared greater than 50% similarity (Figure 5.4). These 47 samples were collected from along all three depth contours and included all four grabs from 11 geographically-close sites (i.e., E5, E7, E8, E11, E15, E17, E19, E20, E23, E25, E26) and three grabs from a twelfth site (i.e., E21). The only site surveyed located within this geographically-defined group whose invertebrate community differed substantially was E14, a nearfield site located <150 m west of the outfall wye. Three of the grabs from E14 shared only ~30% similarity with any other site, and clustered together as an outgroup to the rest of the sites sampled (Figure 5.4). The fourth grab, collected from E14 in January, possessed invertebrate communities similar to the large main clade (clade 1 in Figure 5.4) described above. A sediment sample corresponding to this one January grab was not collected (see Materials and Methods); however, the presence of organisms associated with finer sediments in this grab (e.g., the ophiuroid *Amphiodia urtica*) suggests that benthic substrates where this sample occurred were more similar to the sediments found in clade 1 than in the other three E14 grabs. In general, sediment conditions at station E14 tend to be highly variable and patchy, possibly due to coarse material deposited in the area at the time of outfall construction, and/or unique hydrodynamic activities and scouring of sediments around the physical structure of the pipe.

Cluster analysis revealed the five northern-most sites sampled (B8, B9, B10, B11, B12) to possess benthic communities distinct from each other and all other sites surveyed (Figure 5.4). Except for B10, the four grabs from each site shared a high degree of similarity, allowing each of these northern sites to form its own distinct clade in the dendrogram. Inter-seasonal grabs from site B10 were distinct, each falling into a different clade. Four southern sites (E1, E2, E3, E9) also formed clades unique from all other sites surveyed. Benthic invertebrate communities at E1 and E2 were distinct, with the four grabs from each site sharing a high degree of intra-site similarity. Invertebrate communities from E3 and E9, both occurring along the 116-m contour, shared similarities, and grabs from both sites commingled in the dendrogram.

Although ANOSIM revealed invertebrate communities among many PLOO sites to be

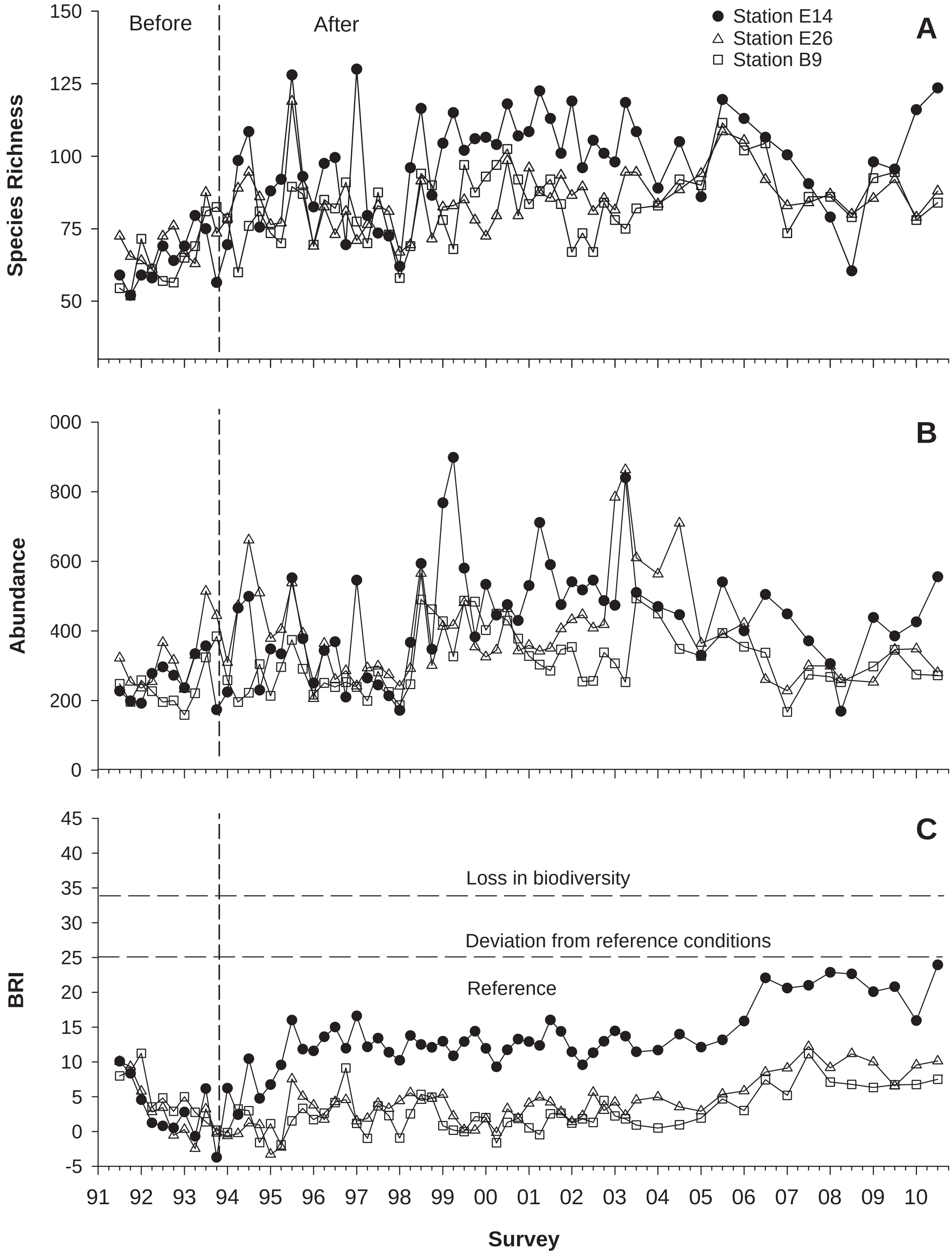


Figure 5.3

Comparison of several parameters at "impact" site (station E14) and "control" sites (stations E26, B9) used in BACIP analyses (see Table 5.4). Parameters include: (A) species richness; (B) infaunal abundance; (C) benthic response index (BRI); (D) abundance of *Ampelisca* spp; (E) abundance of *Amphiodia* spp. Data for each station are expressed as means per 0.1 m^2 ($n = 2$ per survey).

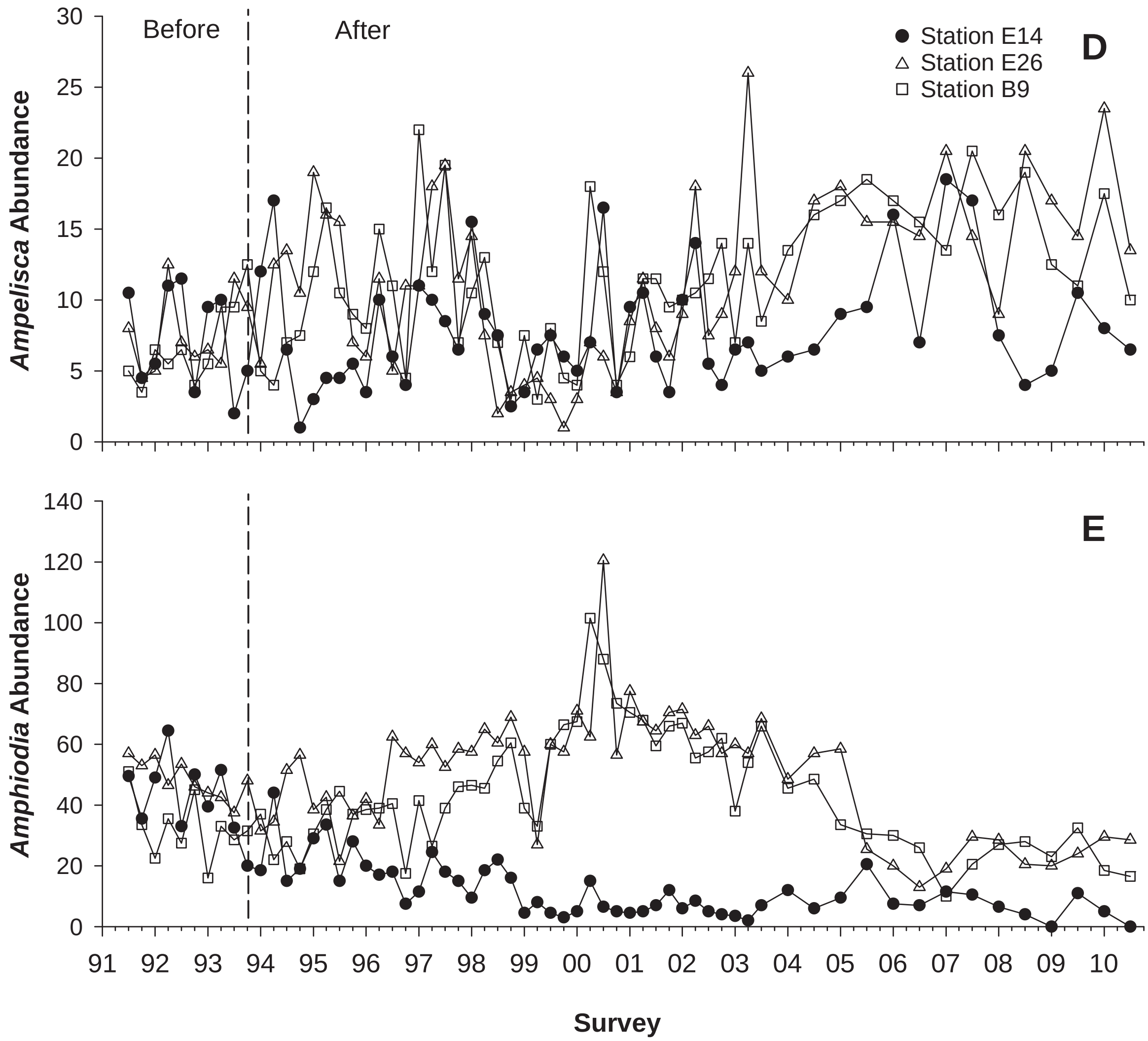


Figure 5.3 *continued*

statistically distinct, a site-level SIMPER indicated that the mix of species occurring at many stations was similar. Thus, it was often not invertebrate diversity that differed significantly among sites, but differences in species abundance. As an example, Appendix D.2 shows that although the presence of many species was ubiquitous across all PLOO sites sampled, the number of individuals recorded from each site differed substantially. In fact, with few exceptions (see below), there were so many minor differences in species abundances among sites that no one or two species could clearly explain why sites differed from each other. Instead, the vast majority of species identified at each site accounted for < 1% of differences between sites, and abundances of well over 200 species were required to describe 90% of the variation observed between sites.

As stated above, a few distinct differences among species diversity or abundance did occur that partially explained the statistically-supported clades found in Figure 5.4. For example, one January grab from site E21 was depauperate in species that occurred ubiquitously in all other grabs from both seasons sampled, but the low diversity in this one grab could have occurred by chance. However, station E14 (located next to the PLOO) consistently contained high abundances of the polychaetes *Capitella teleta*, *Notomastus* sp A, and species of *Polycirrus*, and relatively low abundances of the arthropods *Ampelisca pacifica* and *Eyakia robusta* and the echinoderms *Amphiodia digitata* and *A. urtica* when compared to other sites surveyed (Appendix D.2). These differences, especially the presence of *C. teleta*, are likely due to outfall discharge (Reish 1957, Pearson and

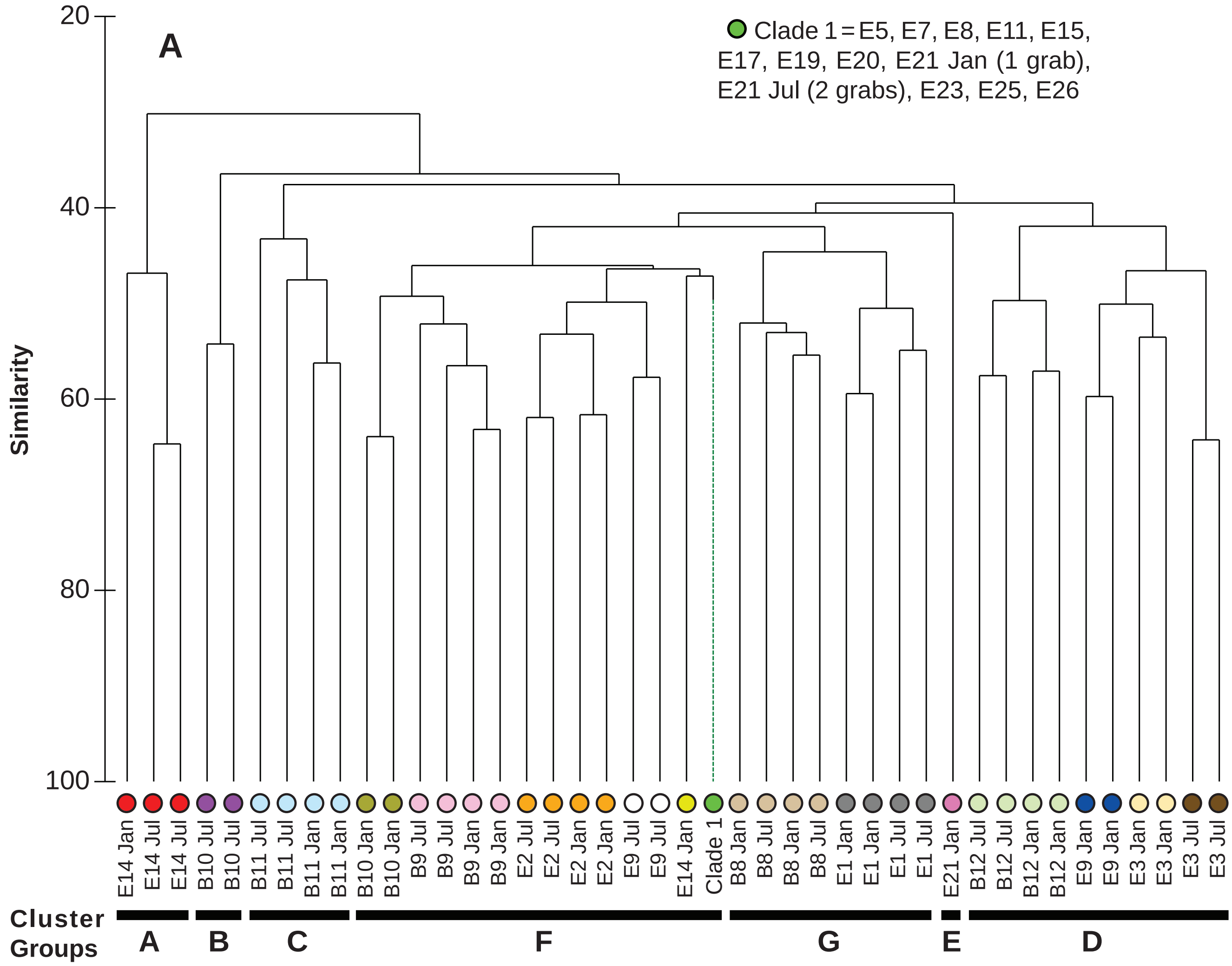


Figure 5.4

Results of multivariate analyses of macrofaunal assemblages at PLOO stations in 2010. (A) Cluster dendrogram depicting relationship of sites. Four grabs (two grabs in both January and July 2010) were collected from each of the 22 surveyed sites. Horizontal bold lines indicate cluster groups retained within 41% similarity. (B) Spatial distribution of macrobenthic assemblages delineated by cluster analysis. Each quarter circle represents a single grab. Colors within each quarter circle correspond to colors in dendrogram.

Rosenberg 1978). Two of the southern 116-m sites (i.e., E3, E9) and one northern 98-m site (i.e., B12) that formed a supported clade in the dendrogram (Figure 5.4) shared the only recorded populations of the gastropod *Micranellum crebricinctum*, and contained among the highest abundances of the ophiuroid *A. digitata* (Appendix D.2), likely due to the presence of coarse sediments.

Even though many sites possessed macroinvertebrate communities that differed significantly, cluster analysis revealed which sites shared the greatest similarity to each other. In order to assess broad-scale invertebrate community attributes and explore physical environmental factors that potentially influence community relatedness, clades in the cluster dendrogram were compressed at the 41% similarity level, resulting in six retained cluster groups (cluster groups A–G; Figure 5.4A). Average invertebrate abundance by taxon was determined for each cluster, and a SIMPER analysis conducted by cluster group to identify the characteristic species found within each assemblage (the most characteristic species are not always the most abundant). For single sample cluster groups (i.e., cluster group E), the most abundant taxa were used to characterize the assemblages. A

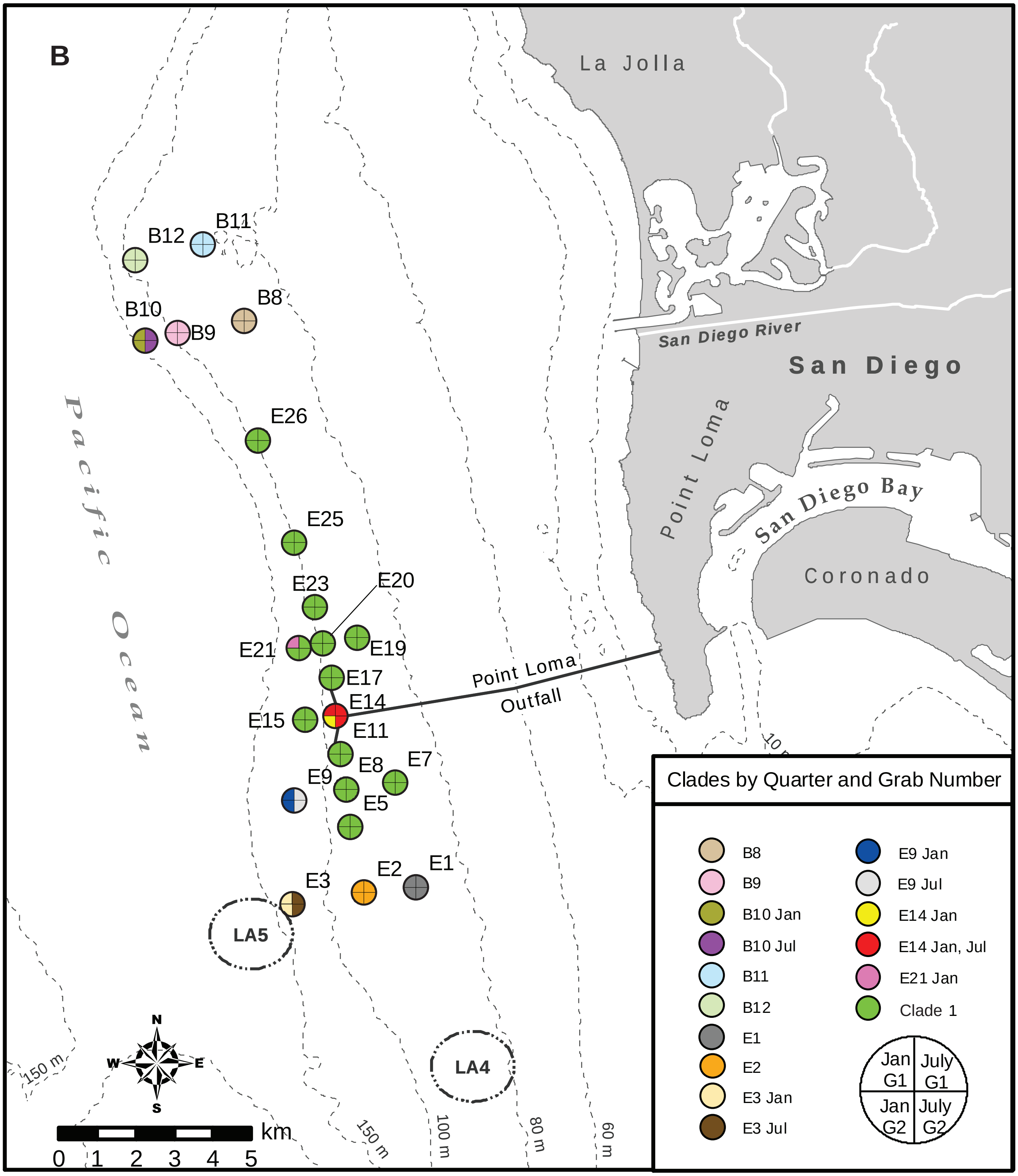


Figure 5.4 *continued*

matrix composed of the five most abundant species for each cluster group as defined above are presented in Table 5.5. A list of species identified by SIMPER as discriminating between individual cluster groups can be found in Appendix D.3. Overall, clusters were similar and no single species strongly discriminated between groups.

Cluster group A was composed of three grabs from station E14, located within a few hundred

Table 5.5

Description of cluster groups A–G defined in Figure 5.4. Data for species richness and infaunal abundance are expressed as mean values per 0.1-m^2 over all stations in each group. The five most abundant species in each cluster are represented. Bold values indicate taxa that were considered among the most characteristic of that group according to SIMPER analysis (i.e., greatest percentage contribution to within-group similarity).

	Group A	Group B	Group C	Group D	Group E	Group F	Group G
Number of Grabs	3	2	4	10	1	60	8
Species Richness	124	104	118	102	56	90	74
Abundance	510	326	331	280	140	320	257
Taxa				**Mean Abundance**			
Polycirrus sp	40.3	9.0	4.8	2.4		3.7	0.6
Notomastus sp A	**27.3**	1.5	1.0	1.0		0.3	0.1
Decamastus gracilis	**26.3**	8.0	1.0	3.9	1.0	2.1	0.1
Chloeia pinnata	25.3	**8.5**	2.0	7.0		3.0	0.1
Aphelochaeta glandaria Cmplx	18.3	**28.5**	1.8	4.8	3.0	6.2	1.0
Axinopsida serricata	6.7	**15.5**	**31.5**	4.5		10.3	14.9
Aphelochaeta monilaris	1.0	**11.5**	2.3	1.2		3.4	1.1
Aricidea (*Acmira*) *rubra*	5.0	**11.0**				1.0	
Adontorhina cyclia	0.3	2.0	**22.8**	1.0		4.0	11.3
Chaetozone hartmanae	13.0	5.5	**14.3**	1.8	4.0	**8.2**	1.0
Aphelochaeta sp LA1	2.0	6.0	**8.5**	4.8	1.0	2.8	1.5
Dipolydora socialis	1.0		7.3	0.2		0.3	
Monticellina siblina	5.3	7.0	2.8	**12.0**	1.0	1.5	0.6
Amphiodia digitata		3.0	0.3	**11.3**		0.8	0.3
Lysippe sp A	2.7	0.5	3.3	**8.3**	7.0	5.2	2.3
Polycirrus sp A	6.0		4.3	**8.0**	8.0	**11.6**	3.8
Aricidea (*Acmira*) *lopezi*			0.3	7.4		4.1	1.3
Amphiodia urtica		1.5	4.8	3.6	14.0	**26.2**	**76.0**
Mediomastus sp	5.0	6.0	4.3	5.0	12.0	7.6	1.3
Lumbrineris sp Group I	2.0	1.0	0.3	1.3	7.0	6.1	2.3
Euphilomedes producta		3.5	0.3	**6.6**	6.0	**13.1**	0.4
Aricidea (*Acmira*) *catherinae*	3.0	2.5	1.8	5.0	1.0	**10.3**	1.1
Ennucula tenuis	0.3	1.5	**6.0**	1.8		3.5	**7.8**
Travisia brevis			2.3	1.5		2.4	6.0

meters of the PLOO along the 98-m depth contour (Figure 5.4B). Average species richness and mean abundance were 124 taxa and 510 individuals/grab, respectively. July sediments for this cluster consisted of 52.9% coarse, 30.2% sand, and only 16.8% fines. The most abundant species encountered were the polychaetes *Polycirrus* sp A, *Notomastus* sp A, *Decamastus gracilis* and *Chloeia pinnata* (Table 5.5). SIMPER revealed the polychaetes *Notomastus* sp A, *Decamastus gracilis*, *Capitella teleta* and Euclymeninae, and the bivalve *Parvilucina tenuisculpta* to be the five most characteristic species that defined the cluster group.

Cluster group B consisted of two grabs collected from station B10 in July along the 116-m depth contour (Figure 5.4B). Average species richness and mean abundance were 104 taxa and 326 individuals/grab, respectively. Sediments consisted of 31.5% fines. The most abundant species encountered included polychaetes from the *Aphelochaeta glandaria* complex, *Aphelochaeta monilaris*, and *Aricidea* (*Acmira*) *rubra*, and the bivalve *Axinopsida serricata* (Table 5.5). SIMPER revealed that the four most abundant taxa listed above and *Chloeia pinnata* were the five most characteristic species that defined these assemblages.

Cluster group C consisted of all four grabs collected throughout the year from station B11, situated along the 88-m depth contour (Figure 5.4B). Average species richness and mean abundance were 118 taxa and 331 individuals/grab, respectively. Sediments from two separate grabs ranged from 1.7%−28.5% coarse (mean = 15.1%), 29.3%−46.5% sand (mean = 37.9%) and 42.2%−51.8% fines (mean = 47.0%). The most abundant species included the molluscs *Axinopsida serricata* and *Adontorhina cyclia* (Table 5.5). The five most characteristic invertebrates found in these assemblages included the polychaetes *Chaetozone hartmanae* and *Aphelochaeta* sp LA1, and the molluscs *A. serricata*, *A. cyclia* and *Ennucula tenuis*.

Cluster group D contained assemblages from ten samples located along the 98 and 116-m depth contours. Average species richness and mean abundance were 102 taxa and 280 individuals/grab, respectively. Sediments ranged from 0−13.9% coarse (mean = 2.8%), 56.1%−70.2% sand (mean = 64.5%) and 15.9%−43.9% fines (mean = 32.7%). The polychaete *Monticellina siblina* and the echinoderm *Amphiodia digitata* were the most abundant species encountered (Table 5.5). In addition to the two most abundant species listed above, the arthropod *Euphilomedes producta* and the polychaetes *Lysippe* sp A and *Polycirrus* sp A were the most characteristic taxa for the cluster group.

Group E comprised a single grab from station E21 collected in January along the 116-m depth contour (Figure 5.4B). Species richness and abundance were 56 taxa and 140 individuals, respectively. No sediments were collected along with this grab. The most abundant taxa found in the grab included the echinoderm *Amphiodia urtica*, and the polychaetes *Mediomastus* sp, *Polycirrus* sp A, *Lysippe* sp A, and *Lumbrineris* sp Group 1 (Table 5.5). As discussed in the detailed description of cluster analysis (above), this group was characterized by the absence of common species (e.g. *Aphelochaeta monilaris*, *Axinopsida serricata*) rather than abundance of organisms present.

Cluster group F was the main assemblage and consisted of 68% of grabs collected during 2010 and encompassed sites from all depth contours (Figure 5.4B). Average species richness and mean abundance were 90 taxa and 320 individuals/grab, respectively. Coarse sediments ranged from 0−1.3% (mean = 0.1%), sand ranged from 52.6%−70.5% (mean = 62.1%), and fines ranged from 29.5%−47.4% (mean = 37.8%). The most abundant organism that defined these sites was the ophiuroid *Amphiodia urtica* (Table 5.5). PRIMER revealed the five most characteristic species for the clade to be *A. urtica*, the arthropod *Euphilomedes producta*, and the polychaetes *Polycirrus* sp A, *Aricidea* (*Acmira*) *catherinae*, and *Chaetozone hartmanae*.

Cluster group G comprised all grabs from stations E1 and B8 located along the 88-m depth contour. Average species richness and mean abundance were 74 taxa and 257 individuals/grab, respectively. Sediment composition ranged from 0−1.1% coarse (mean = 0.3%), 41.7%−58.7% sand (mean = 50.0%), and 40.2%−58.3% fines (mean = 50.0%). As with cluster group F, the most abundant species collected was *Amphiodia urtica* (Table 5.5). The five most characteristic taxa for this group included *A. urtica*, the mollusc *Ennucula tenuis*, the polychaetes *Clymenura gracilis* and *Proclea* sp A, and the amphipod *Rhepoxynius bicuspidatus*.

Discussion

As in previous sampling years, benthic communities surrounding the PLOO in 2010 continued to be dominated by ophiuroid-polychaete based assemblages, with few major changes having occurred since monitoring began (City of San Diego 1995, 1999, 2010). The brittle star *Amphiodia urtica* was the most abundant and widespread species, while the bivalve *Axinopsida serricata* was the second most widespread benthic invertebrate. Many sites surveyed off Point Loma during the year were found to possess species assemblages similar to those described for other areas in the Southern California Bight (SCB) by Barnard and Ziesenhenne (1961), Jones (1969), Fauchald and Jones (1979), Thompson et al. (1987, 1993a), Zmarzly et al. (1994), Diener and

Fuller (1995), Bergen et al. (1998, 2000, 2001), and others. However, even though overall diversity was similar among sites, the relative abundance of specific species often varied depending mostly on sediment type or proximity to the discharge site, which led to many of the significant differences documented via multivariate analysis.

Abundance and dominance of select species (e.g., *Amphiodia urtica*) in benthic macroinvertebrate communities off Point Loma have generally remained static at most sites since monitoring began in 1991 (e.g., City of San Diego 1995, 1999, 2007). Additionally, values for these parameters in 2010 were within the range of those described for other sites throughout the SCB (Thompson et al. 1993b, Bergen et al. 1998, 2000, 2001, Ranasinghe et al. 2003, 2007). In spite of this overall stability, an increase in the abundance of a few species documented at stations located adjacent to the PLOO during the post-discharge period may be indicative of organic enrichment or other types of disturbance that have destabilized the benthic community (Warwick and Clarke 1993, Zmarzly et al. 1994). For example, BRI values have increased at near-ZID station E14 since discharge began as well as at two other nearfield stations (E11 and E17), likely because of limited organic enrichment to the area. However, despite these increases, overall BRI values in the PLOO region remain indicative of relatively undisturbed areas (Smith et al. 2001, Ranasinghe et al. 2010). Additionally, there have been changes in sediment composition at station E14 possibly related to construction of the PLOO (see Chapter 4 herein, City of San Diego 2007) that likely influenced invertebrate community structure near the outfall due to localized physical disturbances.

Specific changes to indicator taxa that may correspond to organic enrichment near the outfall include a decrease in brittle star, *Amphiodia urtica*, populations at station E14 since discharge began, while concomitant increases in abundances of this brittle star occurred at reference sites from 1997 to 2006. Although long term changes in *Amphiodia* populations at E14 may be related to organic enrichment, factors such as altered sediment composition and increased predation pressure near the outfall may also be important. Regardless of the cause of these changes, abundances of *Amphiodia* off Point Loma still remain within the range of natural variation in the SCB.

Recent increases in populations of the opportunistic polychaete *Capitella teleta* may also be indicative of changing benthic conditions nearest the discharge site. For example, a total of 92 individuals of *C. teleta* were reported across the entire PLOO region in 2010 of which 95% occurred at the four nearfield stations located within 750 m of the discharge site. At these locations, *C. teleta* averaged 6.2 individuals per site, with the greatest concentration occurring at station E14 adjacent to the outfall (72 individuals, averaging 18 individuals per grab). Although these abundances represented a noticeable change, they are still much lower than the high densities (e.g., $>500/0.1\ m^2$) associated with polluted sediments reported elsewhere in the SCB (Swartz et al. 1986). Natural population fluctuations of other resident polychaetes commonly occur off San Diego (Zmarzly et al. 1994, Diener et al. 1995) and are not likely an effect of wastewater discharge. Further complicating the picture, relatively stable populations of pollution-sensitive amphipods in the genus *Rhepoxynius* at station E14 suggest the outfall has little to no effect on these indicator species.

In conclusion, while it is difficult to detect specific effects of wastewater discharge via the PLOO on the marine benthos off San Diego, it is possible to see some changes occurring nearest the discharge site. Because of the minimal extent of these changes, it has not been possible to determine whether observed effects are due to habitat alteration related to organic enrichment, the physical structure of the outfall pipe, or a combination of factors. In addition, abundances of soft bottom invertebrates naturally exhibit substantial spatial and temporal variability that may mask the effects of any disturbance event (Morrisey et al. 1992a, 1992b, Otway 1995). The effects associated with the discharge of advanced primary treated sewage may be difficult to detect in areas subjected to strong currents that facilitate the dispersion of the wastewater plume (Diener and Fuller 1995). Although some changes in macrobenthic assemblages have appeared near the outfall, most assemblages in the Point Loma region remain similar to those observed prior to discharge and to the natural indigenous communities characteristic of the southern California continental shelf. Overall, benthic macrofauna appear to be in good condition off Point Loma, with all of the sites surveyed in 2010 being classified in reference condition based on assessments using the benthic response index. This is not unexpected as Ranasinghe et al. (2010) recently reported that 98% of the entire SCB remains in good condition based on data gathered during the 1994, 1998, and 2003 bight-wide surveys.

Literature Cited

Barnard, J.L. and F.C. Ziesenhenne. (1961). Ophiuroidea communities of southern Californian coastal bottoms. Pacific Naturalist, 2: 131–152.

Bergen, M., D.B. Cadien, A. Dalkey, D.E. Montagne, R.W. Smith, J.K. Stull, R.G. Velarde, and S.B. Weisberg. (2000). Assessment of benthic infaunal condition on the mainland shelf of southern California. Environmental Monitoring Assessment, 64: 421–434.

Bergen, M., S.B. Weisberg, D. Cadien, A. Dalkey, D. Montagne, R.W. Smith, J.K. Stull, and R.G. Velarde. (1998). Southern California Bight 1994 Pilot Project: IV. Benthic Infauna. Southern California Coastal Water Research Project, Westminster, CA.

Bergen, M., S.B. Weisberg, R.W. Smith, D.B. Cadien, A. Dalkey, D.E. Montagne, J.K. Stull, R.G. Velarde, and J.A. Ranasinghe. (2001). Relationship between depth, sediment, latitude, and the structure of benthic infaunal assemblages on the mainland shelf of southern California. Marine Biology, 138: 637–647.

Bernstein, B.B. and J. Zalinski. (1983). An optimum sampling design and power tests for environmental biologists. Journal of Environmental Management, 16: 35–43.

Bilyard, G.R. (1987). The value of benthic infauna in marine pollution monitoring studies. Marine Pollution Bulletin, 18(11): 581–585.

City of San Diego. (1995). Outfall Extension Pre-Construction Monitoring Report. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (1999). San Diego Regional Monitoring Report for 1994–1997. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2007). Appendix E. Benthic Sediments and Organisms. In: Application for Renewal of NPDES CA0107409 and 301(h) Modified Secondary Treatment Requirements, Point Loma Ocean Outfall. Volume IV, Appendices A thru F. Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2009. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Clarke, K.R. and R.N. Gorley. (2006). PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth.

Clarke, K.R., P.J. Somerfield, and R.N. Gorley. (2008). Testing of null hypotheses in exploratory community analyses: similarity profiles and biota-environment linkage. Journal of Experimental Marine Biology and Ecology, 366: 56–69.

Clarke, K.R., and Warwick RM (2001). Change in marine communities: an approach to statistical analysis and interpretation, 2nd edition. PRIMER-E, Plymouth.

Diener, D.R. and S.C. Fuller. (1995). Infaunal patterns in the vicinity of a small coastal wastewater outfall and the lack of infaunal community response to secondary treatment. Bulletin of the Southern California Academy of Science, 94: 5–20.

Diener, D.R., S.C. Fuller, A. Lissner, C.I. Haydock, D. Maurer, G. Robertson, and R. Gerlinger. (1995). Spatial and temporal patterns of the infaunal community near a major ocean outfall in southern California. Marine Pollution Bulletin, 30: 861–878.

Fauchald, K. and G.F. Jones. (1979). Variation in community structures on shelf, slope, and basin macrofaunal communities of the Southern California Bight. Report 19, Series 2. In: Southern California Outer Continental Shelf Environmental Baseline Study, 1976/1977 (Second Year) Benthic Program. Principal Investigators Reports, Vol. II. Science Applications, Inc. La Jolla, CA.

Ferraro, S.P., R.C. Swartz, F.A. Cole, and W.A. Deben. (1994). Optimum macrobenthic sampling protocol for detecting pollution impacts in the Southern California Bight. Environmental Monitoring and Assessment, 29: 127–153.

Gray, J.S. (1979). Pollution-induced changes in populations. Philosophical Transactions of the Royal Society of London (Series B.), 286: 545–561.

Hartley, J.P. (1982). Methods for monitoring offshore macrobenthos. Marine Pollution Bulletin, 12: 150–154.

Jones, G.F. (1969). The benthic macrofauna of the mainland shelf of southern California. Allan Hancock Monographs of Marine Biology, 4: 1–219.

Morrisey, D.J., L. Howitt, A.J. Underwood, and J.S. Stark. (1992a). Spatial variation in soft-sediment benthos. Marine Ecology Progress Series, 81: 197–204.

Morrisey, D.J., A.J. Underwood, L. Howitt, and J.S. Stark. (1992b). Temporal variation in soft-sediment benthos. Journal of Experimental Marine Biology and Ecology, 164: 233–245.

Osenberg, C.W., R.J. Schmitt, S.J. Holbrook, K.E. Abu-Saba, and A.R. Flegel. (1994). Detection of environmental impacts: Natural variability, effect size, and power analysis. Ecological Applications, 4: 16–30.

Otway, N.M. (1995). Assessing impacts of deepwater sewage disposal: a case study from New South Wales, Australia. Marine Pollution Bulletin, 31: 347–354.

Pearson, T.H. and R. Rosenberg. (1978). Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanography and Marine Biology Annual Review, 16: 229–311.

Ranasinghe, J.A., A.M. Barnett, K. Schiff, D.E. Montagne, C. Brantley, C. Beegan, D.B. Cadien, C. Cash, G.B. Deets, D.R. Diener, T.K. Mikel, R.W. Smith, R.G. Velarde, S.D. Watts, S.B. Weisberg. (2007). Southern California Bight 2003 Regional Monitoring Program: III. Benthic Macrofauna. Southern California Coastal Water Research Project. Costa Mesa, CA.

Ranasinghe, J.A., D.E. Montagne, R.W. Smith, T.K. Mikel, S.B. Weisberg, D. Cadien, R. Velarde, and A. Dalkey. (2003). Southern California Bight 1998 Regional Monitoring

Program: VII. Benthic Macrofauna. Southern California Coastal Water Research Project. Westminster, CA.

Ranasinghe, J.A., K.C. Schiff, D.E. Montagne, T.K. Mikel, D.B. Cadien, R.G. Velarde, and C.A. Brantley. (2010). Benthic macrofaunal community condition in the Southern California Bight, 1994–2003. Marine Pollution Bulletin, 60: 827–833.

Reish, D.J. (1957). The Relationship of Polychaetous Annelid Capitella capitata (Fabricus) to Waste Discharges of Biological Origin. Public Health Reports 208: 195-200

Smith, R.W., M. Bergen, S.B. Weisberg, D. Cadien, A. Dalkey, D. Montagne, J.K. Stull, and R.G. Velarde. (2001). Benthic response index for assessing infaunal communities on the southern California mainland shelf. Ecological Applications, 11(4): 1073–1087.

Smith, R.W. and L. Riege. (1994). Optimization and power analyses for the Point Loma monitoring design. Unpublished report to City of San Diego, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Snelgrove P.V.R., T.H. Blackburn, P.A. Hutchings, D.M. Alongi, J.F. Grassle, H. Hummel, G. King, I. Koike, P.J.D. Lambshead, N.B. Ramsing, V. Solis-Weiss. (1997). The importance of marine sediment biodiversity in ecosystem processes. Ambio, 26: 578–583.

Stewart-Oaten, A., W.W. Murdoch, and K.R. Parker. (1986). Environmental impact assessment: "Pseudoreplication" in time? Ecology, 67: 929–940.

Stewart-Oaten, A., J.R. Bence, and C.W. Osenberg. (1992). Assessing effects of unreplicated perturbations: no simple solutions. Ecology, 73: 1396–1404.

Swartz, R.C., F.A. Cole, and W.A. Deben. (1986). Ecological changes in the Southern California Bight near a large sewage outfall: benthic conditions in 1980 and 1983. Marine Ecology Progress Series, 31: 1–13.

Thompson, B.E., J. Dixon, S. Schroeter, and D.J. Reish. (1993a). Chapter 8. Benthic invertebrates. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. p 369–458.

Thompson, B.E., J.D. Laughlin, and D.T. Tsukada. (1987). 1985 reference site survey. Technical Report No. 221, Southern California Coastal Water Research Project, Long Beach, CA.

Thompson, B.E., D. Tsukada, and D. O'Donohue. (1993b). 1990 reference site survey. Technical Report No. 269, Southern California Coastal Water Research Project, Long Beach CA.

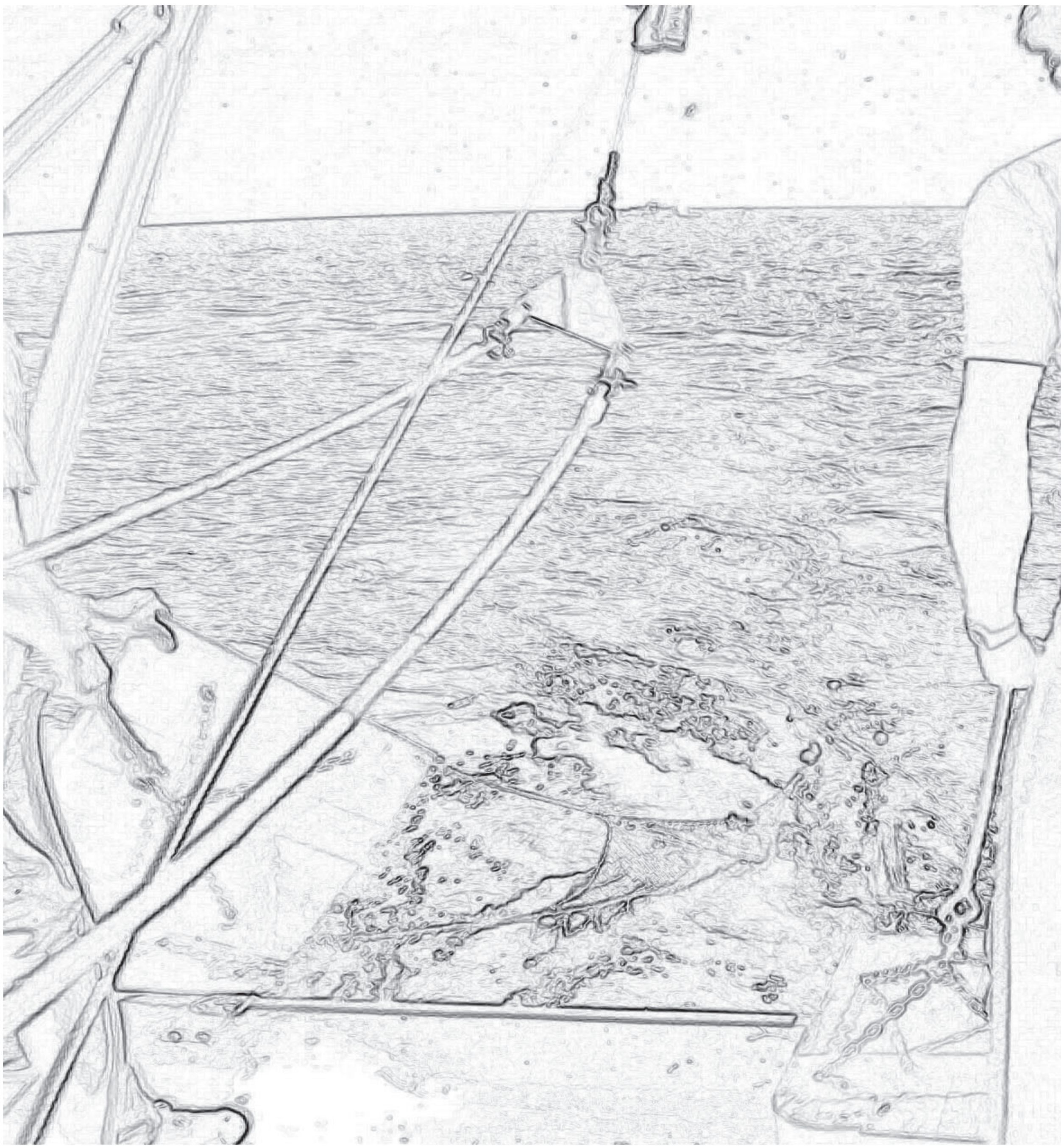
[USEPA] United States Environmental Protection Agency. (1987). Quality Assurance and Quality Control (QA/QC) for 301(h) Monitoring Programs: Guidance on Field and Laboratory Methods. EPA Document 430/9-86-004. Office of Marine and Estuarine Protection.

Warwick, R.M. and K.R. Clarke. (1993). Increased variability as a symptom of stress in marine communities. Journal of Experimental Marine Biology and Ecology, 172: 215–226.

Zmarzly, D.L., T.D. Stebbins, D. Pasko, R.M. Duggan, and K.L. Barwick. (1994). Spatial patterns and temporal succession in soft-bottom macroinvertebrate assemblages surrounding an ocean outfall on the southern San Diego shelf: Relation to anthropogenic and natural events. Marine Biology, 118: 293–307.

This page intentionally left blank

Chapter 6
Demersal Fishes and Megabenthic Invertebrates



Chapter 6. Demersal Fishes and Megabenthic Invertebrates

Introduction

Demersal (bottom dwelling) fishes and relatively large (megabenthic), mobile invertebrates are collected and analyzed for the Point Loma Ocean Outfall (PLOO) monitoring program to evaluate possible effects of wastewater discharge on their communities. These fishes and invertebrates are conspicuous members of continental shelf habitats and are therefore important to the ecology of the southern California coastal shelf, serving vital functions in wide ranging capacities. Because such organisms live in close proximity to the seafloor, they can be impacted by changes in sediments affected by both point and non-point sources (e.g., discharges from ocean outfalls and storm drains, surface runoff from watersheds, outflows from rivers and bays, disposal of dredge materials; see Chapter 4). For these reasons, their assessment has become an important focus of ocean monitoring programs throughout the world, but especially in the Southern California Bight (SCB) where they have been sampled extensively on the mainland shelf (Cross and Allen 1993).

Demersal fishes and megabenthic invertebrate communities are inherently variable and are influenced by many factors. Therefore, distinguishing changes in these communities caused by anthropogenic influences such as the PLOO wastewater discharge from other, more natural, sources is an important aspect of the ocean monitoring program. Natural factors that may affect these organisms include prey availability (Cross et al. 1985), bottom relief and sediment structure (Helvey and Smith 1985), and changes in water temperatures associated with large scale oceanographic events such as El Niño/La Niña oscillations (Karinen et al. 1985). These factors can affect migration patterns of adult fishes or the recruitment of juveniles into an area (Murawski 1993). Population fluctuations that affect species diversity and abundance of both fishes and invertebrates may also be due to the mobile nature of many species (e.g., fish schools, urchin aggregations).

This chapter presents analyses and interpretations of the trawl survey data collected during 2010, as well as a long-term assessment of these communities from 1991 through 2010. The primary goals are to: (1) identify possible effects of wastewater discharge on demersal fishes and megabenthic invertebrates, (2) determine the presence or absence of biological impacts near the discharge site, and (3) identify spatial or temporal trends in demersal community structure in the region.

Materials and Methods

Field Sampling

Trawl surveys were conducted at six fixed monitoring sites in the Point Loma region during January and July 2010 (Figure 6.1). The six trawl stations, designated SD7, SD8, SD10, SD12, SD13 and SD14, are located along the 100-m depth contour, and encompass an area ranging from ~8 km north to 9 km south of the PLOO. A single trawl was performed at each station during each survey using a 7.6-m Marinovich otter trawl fitted with a 1.3-cm cod-end mesh net. The net was towed for 10 minutes bottom time at a speed of about 2.0 knots along a predetermined heading.

The total catch from each trawl was brought onboard ship for sorting and inspection. All fishes and invertebrates captured were identified to species or to the lowest taxon possible. If an animal could not be identified in the field, it was returned to the laboratory for further identification. For fishes, the total number of individuals and total biomass (kg, wet weight) were recorded for each species. Additionally, each individual fish was inspected for physical anomalies or indicators of disease (e.g., tumors, fin erosion, discoloration) as well as the presence of external parasites, and

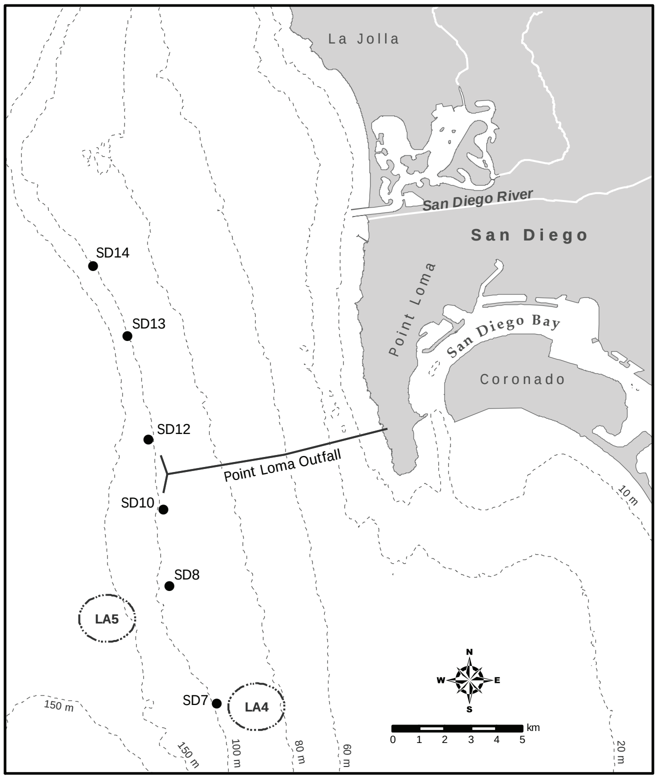


Figure 6.1
Otter trawl station locations, Point Loma Ocean Outfall Monitoring Program.

then measured to the nearest centimeter size class (standard lengths). For invertebrates, the total number of individuals was recorded per species.

Data Analyses

Populations of each fish and invertebrate species were summarized as percent abundance (number of individuals of a single species/total number of individuals of all species), frequency of occurrence (the percentage of stations at which a species was collected), mean abundance per haul (number of individuals of a single species/total number sites sampled), and mean abundance per occurrence (number of individuals of a single species/number of sites at which the species was collected). In addition, species richness (number of taxa), total abundance (number of individuals), and the Shannon diversity index (H') were calculated for both fishes and macroinvertebrates for each station, while total biomass was calculated for just fishes for each station. For historical comparisons the data were grouped as "nearfield" stations (SD10, SD12), "south farfield" stations (SD7, SD8), and "north farfield" stations (SD13, SD14). The two nearfield stations were those located closest to the outfall (i.e., within 1000 m of the north or south diffuser legs).

Multivariate analysis to examine differences of demersal fish communities in the region was performed with data collected from 1991 through 2010. However, to eliminate noise due to natural seasonal variation in populations, data analyzed were restricted to July surveys. PRIMER software was used to test for spatio-temporal differences among fish assemblages from nearfield and farfield locations (Clarke 1993, Warwick 1993, Clarke and Gorley 2006). Prior to analysis, fish abundance data were square root transformed to lessen the influence of prevalent species and increase the weight of rare species, and a Bray-Curtis similarity matrix was created from transformed data with nearfield/farfield locations and year provided as factors. Because species composition was sparse at some stations, a "dummy" species with an abundance value of 1 was added to all samples prior to computing similarities (Clarke and Gorley 2006). A two-way crossed analysis of similarity (ANOSIM; A=nearfield/farfield location, B=year; maximum number of permutations=9999) was conducted to determine whether fish abundances differed between nearfield and farfield locations or years. When significant differences were detected, square-root transformed data were averaged by factor (i.e., nearfield/farfield location, year) and a similarity percentages (SIMPER) analysis was used to identify which fish species accounted for the majority of differences observed. Non-metric multidimensional scaling (nMDS) ordinations and cluster dendrograms were created to visually depict the relationship of averaged data by factor (i.e., nearfield/farfield area, year). Cluster dendrograms were generated using hierarchical agglomerative clustering with group-average linking.

To visually depict relationships among individual sites by year (rather than areas by year) based on fish community composition, a second nMDS ordination and dendrogram were produced. Similarity profile (SIMPROF) analysis was used

Table 6.1

Demersal fish species collected in 12 trawls in the PLOO region during 2010. PA = percent abundance; FO = frequency of occurrence; MAO = mean abundance per occurrence; MAH = mean abundance per haul.

Species	PA	FO	MAO	MAH	Species	PA	FO	MAO	MAH
Pacific sanddab	42	100	191	191	California scorpionfish	< 1	50	4	2
California lizardfish	18	100	80	80	Bigmouth sole	< 1	83	2	1
Yellowchin sculpin	17	75	100	75	California skate	< 1	58	2	1
Longspine combfish	6	100	29	29	Slender sole	< 1	25	5	1
Dover sole	4	75	24	18	Longfin sanddab	< 1	17	7	1
Halfbanded rockfish	3	100	12	12	Hornyhead turbot	< 1	58	2	1
Stripetail rockfish	2	75	14	10	Blackbelly eelpout	< 1	25	3	1
Shortspine combfish	1	92	7	6	Spotted cuskeel	< 1	25	1	< 1
English sole	1	83	7	6	Spotfin sculpin	< 1	8	3	< 1
Plainfin midshipman	1	100	6	6	Blacktip poacher	< 1	17	1	< 1
Roughback sculpin	1	58	7	4	Greenspotted rockfish	< 1	8	2	< 1
Pink seaperch	1	100	3	3	Longnose skate	< 1	8	1	< 1
California tonguefish	1	58	5	3	Rosethorn rockfish	< 1	8	1	< 1
Greenstriped rockfish	< 1	75	3	2					

to confirm non-random structure of the resultant cluster dendrogram (Clarke et al. 2008), and major clusters supported by SIMPROF were subjectively retained for illustrative purposes based on the 0.1 level of significance provided by the SIMPROF analysis. SIMPER analysis was subsequently used to identify which species primarily account for observed differences between cluster groups, as well as to identify species typical of each group.

Results

Demersal Fish Community Parameters

Twenty-seven species of fish were collected in the area surrounding the PLOO in 2010 (Table 6.1, Appendix E.1). The total catch for the year was 5450 individuals, representing an average of ~454 fish per trawl. As in previous years, Pacific sanddabs were dominant, occurring in every haul and accounting for 42% of the total number of fishes collected. California lizardfish, halfbanded rockfish, longspine combfish, plainfin midshipman, and pink seaperch were also collected in every haul, but in much lower numbers. Other species collected frequently (≥75% of the trawls) included yellowchin sculpin, Dover sole, stripetail rockfish, shortspine combfish, English sole, greenstriped rockfish, and bigmouth sole. Pacific sanddabs, yellowchin sculpin, and California lizardfish averaged 191, 100, and 80 individuals per trawl, respectively, while all other species averaged 29 individuals or less per survey and contributed < 6% to the total overall catch. Although the majority of species captured in the Point Loma region tended to be relatively small fishes with an average length ≤20 cm, large individuals of Dover sole, English sole, California scorpionfish and Pacific sanddab that ranged from 22 to 25 cm in length were documented (Appendix E.1).

Species richness of fish from individual hauls ranged from 13 to 19 during 2010, and the corresponding diversity (H') values were all ≤2.0 (Table 6.2). Total abundance of all fish species combined ranged from 337 to 579 fishes per haul. Variation among hauls was driven primarily by differences in the number of yellowchin sculpin, Pacific sanddab, and California lizardfish documented at each station (Appendix E.2). This differed from 2009 where Pacific sanddabs were the only species responsible for the majority of differences observed. In fact, during 2010 surveys, the abundance of California lizardfish was the largest recorded since January 1992 (> 460 individuals caught per sampling period

Table 6.2

Summary of demersal fish community parameters for PLOO trawl stations sampled during 2010. Data are included for species richness (number of species), abundance (number of individuals), diversity (H'), and biomass (kg, wet weight); SD = standard deviation.

Station	January	July
Species Richness		
SD7	15	13
SD8	17	14
SD10	14	19
SD12	16	15
SD13	17	16
SD14	16	18
Survey Mean	16	16
Survey SD	1	2
Abundance		
SD7	419	383
SD8	337	494
SD10	567	419
SD12	471	524
SD13	387	579
SD14	482	388
Survey Mean	444	465
Survey SD	81	80
Diversity		
SD7	1.6	0.9
SD8	2.0	1.1
SD10	1.6	1.6
SD12	2.0	1.6
SD13	1.8	1.2
SD14	1.6	1.1
Survey Mean	1.8	1.3
Survey SD	0.2	0.3
Biomass		
SD7	5.2	4.7
SD8	6.9	4.4
SD10	9.0	9.9
SD12	9.6	10.6
SD13	7.8	7.0
SD14	7.9	6.9
Survey Mean	7.7	7.2
Survey SD	1.6	2.6

in 2010), while the abundance of yellowchin sculpin caught in January (870 individuals) was the largest total recorded since January 2003. Fish biomass ranged from 4.4 to 10.6 kg per haul, with higher values coincident with either greater numbers of fishes or the presence of large individual fish. For example, the maximum biomass recorded at any one station (i.e., SD12) reflects the combined weight of Pacific sanddab (1.6 kg), California lizardfish (2.9 kg), California skate (3.0 kg), and a mixture of other common species (4.7 kg) (Appendix E.3). Over the entire year, the combined maximum weight for common fish species collected within the PLOO region was 23.9 kg for Pacific sanddab, 13.8 kg for California lizardfish, 6.2 kg for California scorpionfish, 5.9 kg for Dover sole, 5.7 kg for California skate, and 6.0 kg for English sole.

Large fluctuations in populations of a few dominant species are the primary factors contributing to the high variation in fish community structure observed off Point Loma since 1991 (Figures 6.2, 6.3). For example, species richness values for individual trawls performed within the PLOO region since 1991 have ranged from 7 to 26 species, while total abundance of fishes per haul has varied from 44 to 2322 individuals/station/survey. Fluctuations in abundance have been greatest at nearfield and northern farfield stations, and generally reflect population differences of the most abundant species: Pacific sanddab, yellowchin sculpin, plainfin midshipman, longspine combfish, Dover sole, longfin sanddab, and halfbanded rockfish (Figure 6.3). Because temporal changes in dominant species are similar between nearfield and northern farfield stations, observed changes in fish populations do not appear to be associated with wastewater discharge.

Classification of Demersal Fish Assemblages

Two-way crossed ANOSIM revealed fish populations to differ among nearfield and farfield areas (Global $R = 0.368$, $p = 0.0001$) and year (Global $R = 0.611$, $p = 0.0001$). Individual pairwise tests found that fish populations at nearfield stations did not differ from either north or south farfield stations ($r = 0.171$ and 0.224, respectively), but that north and south farfield stations possessed fish populations that were significantly different ($r = 0.737$, $p = 0.0001$). Thus, in support of anecdotal

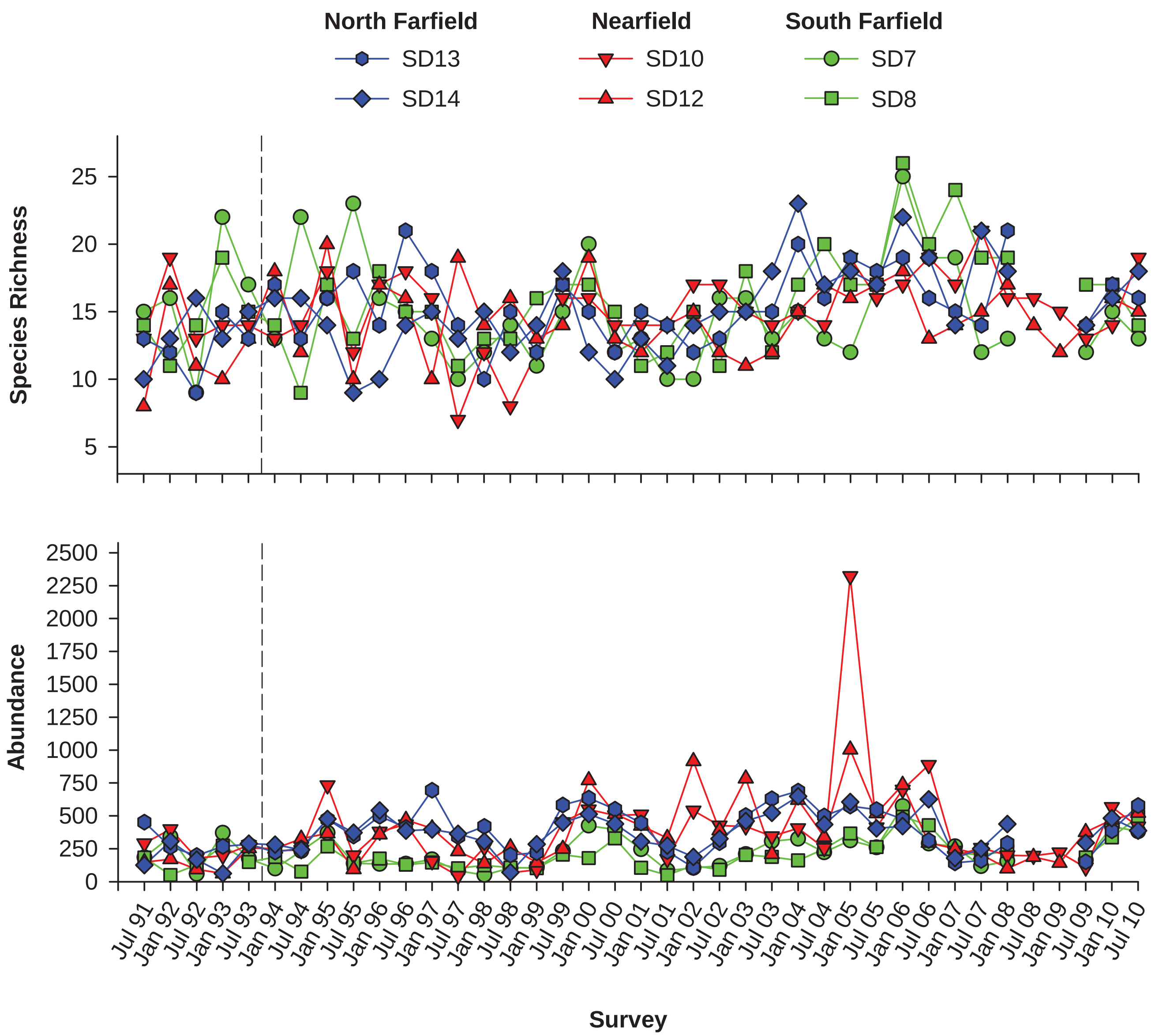


Figure 6.2

Species richness and abundance of demersal fishes collected at each PLOO trawl station between 1991 and 2010. Data are total number of species and total number of individuals per haul, respectively. Dashed line represents initiation of wastewater discharge. Only stations SD10 and SD12 were sampled during July 2008 and January 2009 due to a Bight'08 resource exchange.

observations made since 1991, a gradual gradient exists across the PLOO region that results in fish populations at northern sites being statistically distinct from fish populations at southern sites (Figure 6.1). SIMPER revealed abundances of six fish species whose abundances each contributed to ≥5% of differences observed between north farfield and south farfield stations: Pacific sanddab, stripetail rockfish, plainfin midshipman, halfbanded rockfish, Dover sole, and yellowchin sculpin (Appendix E.4). In all cases, abundances of these fish species were greater at north farfield sites than south farfield sites. nMDS graphically illustrates the annually-persistent gradient in fish populations that has been observed since 1991 among the three nearfield/farfield locations surveyed by depicting distinct clusters of north and south farfield sites commingling with the cloud of nearfield sites (Figure 6.4).

The two-way crossed ANOSIM also revealed 58% of pairwise comparisons among sites by year to

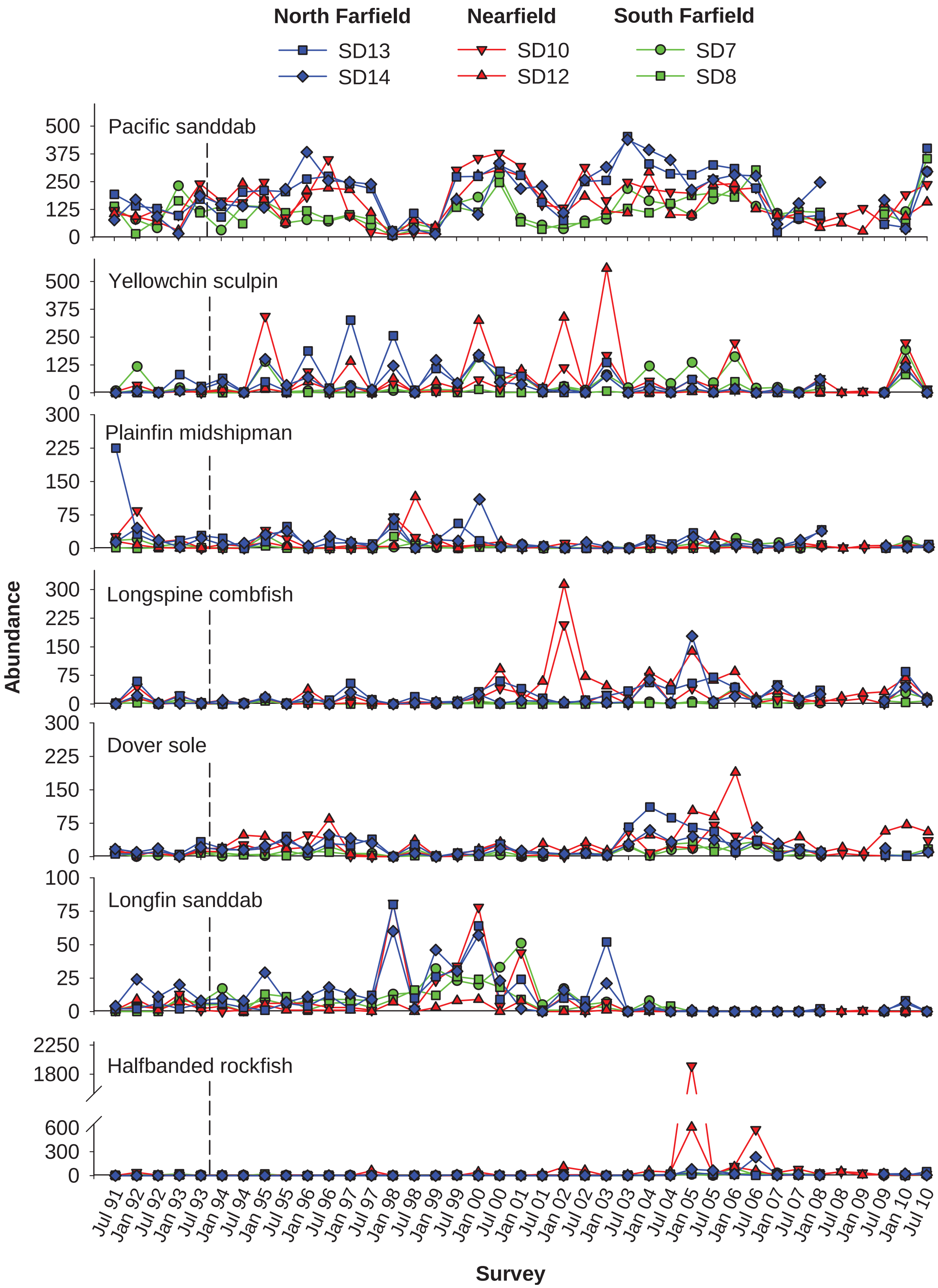


Figure 6.3

The seven most abundant fish species collected in the PLOO region from 1991 through 2010. Data are total number of individuals per haul. Dashed line represents initiation of wastewater discharge. Only stations SD10 and SD12 were sampled during July 2008 and January 2009 due to a Bight'08 resource exchange.

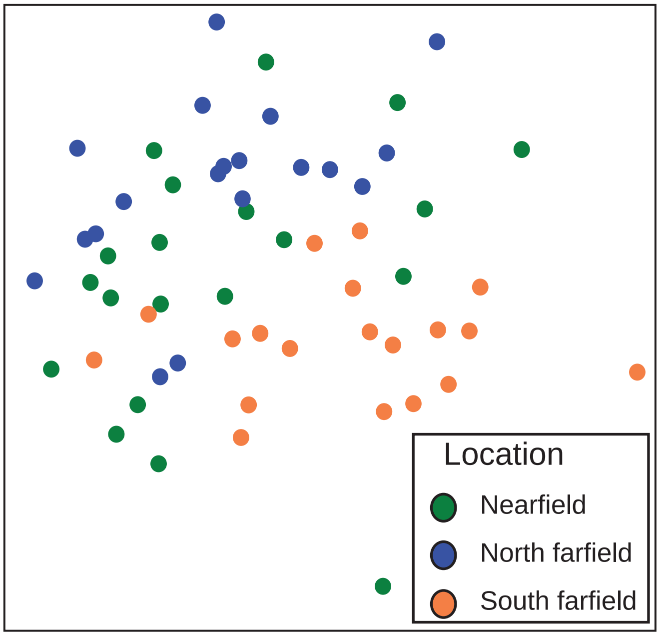


Figure 6.4
nMDS plot depicting relationships among PLOO locations (nearfield, north farfield, south farfield) based on demersal fish abundances for 1991–2010. Stress = 0.19.

be significant, indicating that fish communities differed not only among nearfield/farfield location (as discussed above), but also by survey year. A cluster dendrogram and nMDS ordination reveal that a change in fish populations occurred across the entire PLOO region between 2002 and 2003 (Figure 6.5), with data from 1991–2002 forming one supported cluster, and data from 2003–2010 forming a second supported cluster. Within the 2003–2010 cluster, data from 2008 segregate apart from other years. SIMPER revealed that abundances of five fish species each contributed to ≥4% of differences observed between the two major clades: longfin sanddab, halfbanded rockfish, California lizardfish, greenstriped rockfish, and bay goby (Appendix E.5). Of the fish species that accounted for 90% of observable differences between the two major clades, 60% exhibited higher abundances from 2002–2010 than from 1991–2002. Within the 2003–2010 clade, data collected from 2008 differ from other years in having no occurrences of stripetail rockfish, California lizardfish, California tonguefish, or hornyhead turbot. Because PLOO wastewater discharge began in 1993, the temporal shift in fish communities observed between 2002 and 2003 is likely driven by natural large-scale oceanographic processes (see Chapter 2) rather than PLOO discharge.

Ten main assemblages were interpreted from cluster analyses when fish abundance data were examined by site from 1991 through 2010 (cluster groups A–J; Figure 6.6). SIMPER results show that the demersal fish communities at all survey locations off Point Loma have been dominated by Pacific sanddabs for almost 20 years, with differences in the relative abundance of this or other common species discriminating between the different interpreted cluster groups (Table 6.3, Appendix E.6). In fact, SIMPER revealed that the mix of species occurring in many cluster-analysis defined groups was similar, and it is often differences in species abundance rather than species diversity that delimited each cluster group. For instance, group C possessed populations of squarespot and greenblotched rockfish that were 77 and 4 times higher than any other group, respectively. Additionally, group C possessed the only site during 20 years of surveys where vermilion rockfish were recorded. As another example, group D possessed populations of longfin sanddab and stripetail rockfish 4 and 10 times higher than any other group.

During 2010, fish assemblages at each station were similar to those reported from 2006 to 2009, with the exception of SD7 in 2007 (Figure 6.6). SIMPER found high abundances of Pacific sanddab, halfbanded rockfish, Dover sole, longspine combfish, and shortspine combfish to differentiate most 2006 through 2010 fish assemblages from assemblages reported from 1991 through 2005. No observable spatial or temporal patterns in fish community structure can be attributed to the outfall or the onset of wastewater discharge. Instead, most differences in local fish assemblages appear to be related to large-scale oceanographic events (e.g., El Niño conditions in 1998) or the unique characteristics of a specific station. For example, fish assemblages at the south farfield stations often grouped apart from the remaining trawl stations (as was also detected by ANOSIM analysis, above).

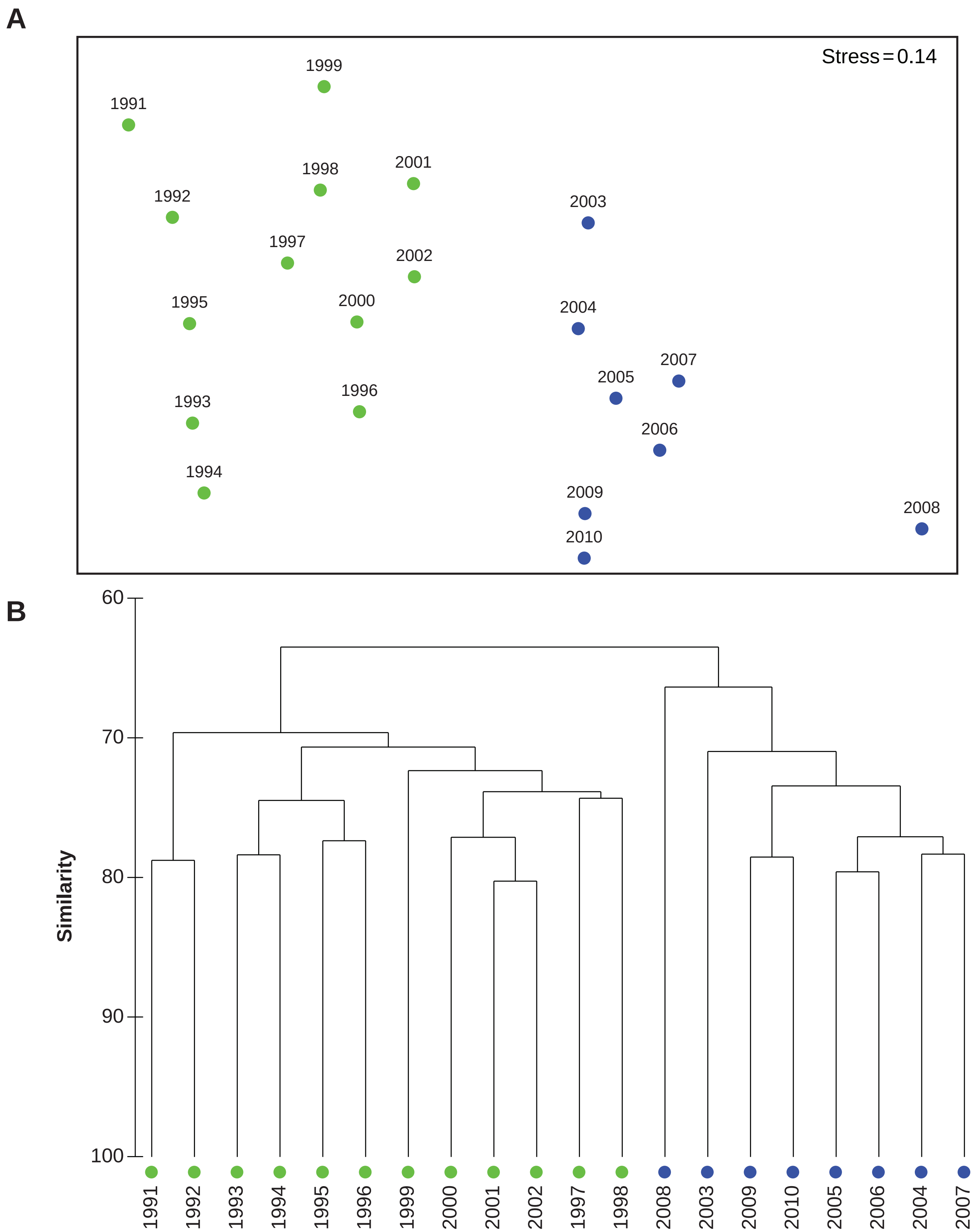


Figure 6.5

Results of classification analysis of demersal fish assemblages collected at PLOO stations by year (July surveys only). Data are presented as (A) nMDS and (B) cluster diagram depicting relationships among years based on averaged demersal fish population abundances found in the PLOO region between 1991 and 2010. Fish populations from 1991–2002 form one supported cluster, while fish populations from 2003–2010 form a second supported cluster.

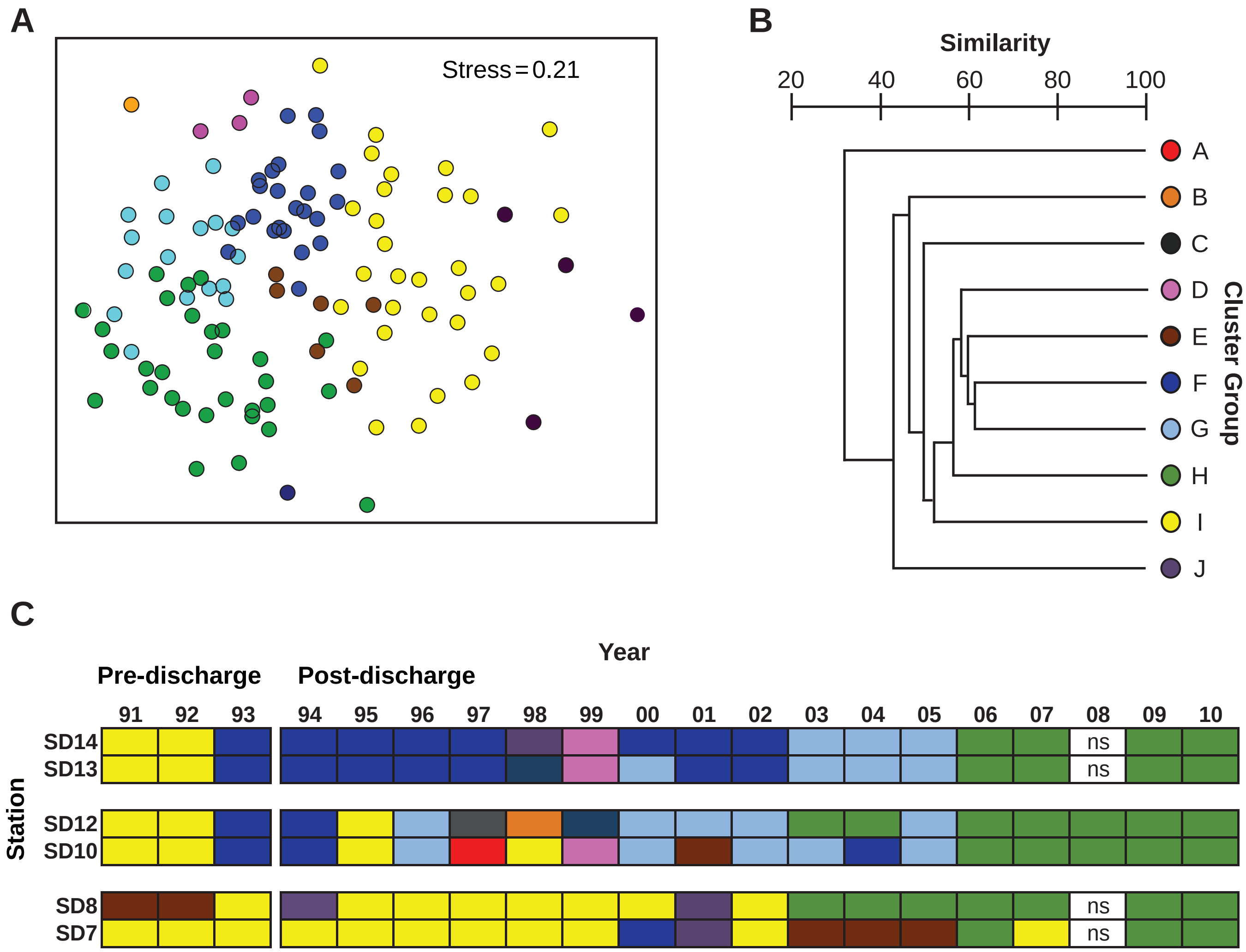


Figure 6.6

Results of classification analysis of demersal fish assemblages collected at PLOO stations SD7–SD14 between 1991 and 2010 (July surveys only). Data are presented as (A) nMDS ordination, (B) a dendrogram of major cluster groups, and (C) a matrix showing distribution of cluster groups over time with stations grouped as "North Farfield" (SD13, SD14), "Nearfield" (SD10, SD12), and "South Farfield" (SD7, SD8); ns = not sampled.

Physical Abnormalities and Parasitism

Demersal fish populations appeared healthy in the PLOO region during 2010. There were no incidences of fin rot, discoloration, skin lesions, tumors or any other indicators of disease among fishes collected during the year. Evidence of parasitism was also very low with only 0.6% of trawl-caught fishes being infested. Pacific sanddabs appeared to be the species most susceptible to parasitism with ~1.4% of the population infected by the copepod *Phrixocephalus cincinnatus*. Overall, fishes from station SD10 exhibited the highest degree of parasitism, with 17 cases reported. Additionally, three individuals of the cymothoid isopod, *Elthusa vulgaris*, were identified as part of the trawl catches over the course of the year (Appendix E.7). Since cymothoids often become detached from their hosts during retrieval and sorting of the trawl catch, it is unknown which fishes were actually parasitized by these isopods. However, *E. vulgaris* is known to be especially common on sanddabs and California lizardfish in southern California waters, where rates of infestation can reach 3% and 80%, respectively (Brusca 1978, 1981).

Table 6.3

Description of cluster groups A–J defined in Figure 6.6. Data include number of hauls, mean species richness, mean total abundance, and mean abundance of the five most abundant species for each station group. Bold values indicate species that were considered among the most "characteristic" of that group according to SIMPER analysis (i.e., greatest percentage contribution to within-group similarity).

	Cluster Groups									
	A	B	C	D	E	F	G	H	I	J
Number of Hauls	1	1	1	3	6	23	17	30	30	4
Mean Species Richness	7	16	19	17	14	14	16	16	13	11
Mean Abundance	44	261	231	495	213	307	467	321	162	71
Species	**Mean Abundance**									
Pacific sanddab	23.0	75.0	110.0	**248.3**	**150.2**	**215.2**	**300.9**	**169.3**	**97.4**	**46.8**
Halfbanded rockfish	16.0		60.0	6.7	2.7	1.2	15.5	**46.3**	1.8	
Longfin sanddab	1.0			**31.7**		7.8	1.0	0.2	6.8	2.0
Pink seaperch	1.0	4.0	1.0	4.0	1.8	5.6	4.4	3.7	0.9	1.0
Spotfin sculpin	1.0						0.5	1.5	2.1	0.8
Gulf sanddab	1.0	5.0		9.7	0.2	0.2	0.1		0.2	0.5
Greenspotted rockfish	1.0		1.0	0.3		0.7	0.3	0.1	0.4	
Stripetail rockfish		1.0	5.0	**102.0**	0.2	10.4	5.8	3.9	8.3	3.8
Dover sole		36.0	1.0	**5.0**	**14.5**	**22.7**	**48.1**	**24.3**	**10.0**	3.3
Yellowchin sculpin				**31.0**	20.0	14.7	16.2	2.2	3.5	2.5
Longspine combfish		7.0	2.0	**5.0**	**2.7**	5.0	32.5	**10.7**	0.7	2.3
Greenblotched rockfish			8.0	1.3	1.8	0.9	1.4	0.3	0.7	1.0
Plainfin midshipman		116.0	4.0	26.0	**2.3**	10.7	5.7	4.1	**14.6**	0.8
California lizardfish				6.0				22.0	0.5	0.5
Squarespot rockfish			23.0					0.1	0.1	0.3
Shortspine combfish			3.0		5.2	0.5	3.6	**10.2**	2.1	
Vermilion rockfish			6.0							

Invertebrate Community

A total of 19,562 megabenthic invertebrates (~1630 per trawl) representing 43 taxa were collected during 2010 (Table 6.4, Appendix E.7). As in previous years, the sea urchin *Lytechinus pictus* was the most abundant and most frequently captured species, occurring in all trawls and accounting for 91% of the total invertebrate abundance. The brittle star *Ophiura luetkenii* was also collected in every haul, but in much lower numbers. Other common species that occurred in 50% or more of the hauls included the sea pen *Acanthoptilum* sp, the sea slug *Pleurobranchaea californica*, the sea cucumber *Parastichopus californicus*, the sea stars *Astropecten verrilli* and *Luidia foliolata*, and the octopus *Octopus rubescens*.

Megabenthic invertebrate community structure varied among stations and between surveys during the year (Table 6.5). Species richness ranged from 7 to 17 species per haul, diversity (H') values ranged from 0.1 to 1.1 per haul, and total abundance ranged from 719 to 3447 individuals per haul. Patterns in total invertebrate abundance mirrored variation in populations of the sea urchin *L. pictus* because of its overwhelming dominance at all stations (with the exception on SD14 in July; Appendix E.8). For example, in January, stations SD8, SD10 and SD12 had much higher invertebrate abundances than the other three

Table 6.4

Species of megabenthic invertebrates collected in 12 trawls in the PLOO region during 2010. PA = percent abundance; FO = frequency of occurrence; MAO = mean abundance per occurrence; MAH = mean abundance per haul.

Species	PA	FO	MAO	MAH	Species	PA	FO	MAO	MAH
Lytechinus pictus	91	100	1477	1477	*Elthusa vulgaris*	<1	17	2	<1
Acanthoptilum sp	5	92	81	74	*Philine alba*	<1	8	3	<1
Strongylocentrotus fragilis	3	33	131	44	*Arctonoe pulchra*	<1	17	1	<1
Ophiura luetkenii	1	100	12	12	*Loxorhynchus grandis*	<1	17	1	<1
Pleurobranchaea californica	<1	67	7	5	*Tritonia diomedea*	<1	17	1	<1
Neosimnia barbarensis	<1	42	6	3	*Antiplanes catalinae*	<1	8	1	<1
Parastichopus californicus	<1	83	3	2	*Astropecten ornatissimus*	<1	8	1	<1
Astropecten verrilli	<1	67	3	2	*Calliostoma turbinum*	<1	8	1	<1
Luidia asthenosoma	<1	33	5	2	*Cancellaria crawfordiana*	<1	8	1	<1
Luidia foliolata	<1	50	3	1	*Dendronotus iris*	<1	8	1	<1
Philine auriformis	<1	42	3	1	*Doris montereyensis*	<1	8	1	<1
Octopus rubescens	<1	58	1	1	*Euspira draconis*	<1	8	1	<1
Sicyonia ingentis	<1	33	3	1	*Florometra serratissima*	<1	8	1	<1
Luidia armata	<1	33	2	1	*Hemisquilla californiensis*	<1	8	1	<1
Suberites latus	<1	42	1	1	*Metacrangon spinosissima*	<1	8	1	<1
Thesea sp B	<1	25	2	1	*Metridium farcimen*	<1	8	1	<1
Armina californica	<1	17	3	1	*Odontaster crassus*	<1	8	1	<1
Rossia pacifica	<1	17	3	1	*Ophiopholis bakeri*	<1	8	1	<1
Paguristes bakeri	<1	33	1	0	*Paguristes turgidus*	<1	8	1	<1
Platymera gaudichaudii	<1	25	1	0	*Platydoris macfarlandi*	<1	8	1	<1
Crangon alaskensis	<1	17	2	0	*Spatangus californicus*	<1	8	1	<1

stations due to relatively large catches of *L. pictus* (i.e., ≥1300/haul). Similarly, low diversity values (≤1.1) for the region were caused by the numerical dominance of this single species. Dominance of *L. pictus* is typical for the types of habitats encountered in the PLOO region and throughout the SCB (Allen et al. 1998).

Invertebrate species richness and abundances have varied temporally since 1991 when surveys began (Figure 6.7). For example, species richness has ranged from 3 to 29 species per year, with overall patterns of change being similar among stations. In contrast, change in total invertebrate abundance has differed greatly among trawl stations. Average annual invertebrate catches have been consistently low at northern farfield stations, while abundances at nearfield and southern farfield stations fluctuated substantially over time. As stated above, these fluctuations typically reflect changes in *L. pictus* populations, although populations of the sea pen *Acanthoptilum* sp, the sea urchin *Strongylocentrotus fragilis*, the shrimp *Sicyonia ingentis*, the sea cucumber *Parastichopus californicus*, and the sea star *Astropecten verrilli* have also varied noticeably (Figure 6.8). Low abundances of *L. pictus* and *A. verrilli* at northern farfield stations likely reflect differences in sediment composition (e.g., fine sands vs. mixed coarse/fine sediments, see Chapter 4). None of the observed variability in the trawl-caught invertebrate community can be related to the discharge of wastewater from the PLOO.

Discussion

Comparison of fish population parameters over 20 years coupled with multivariate analysis provide

Table 6.5
Summary of megabenthic invertebrate community parameters for PLOO trawl stations sampled during 2010. Data are included for species richness (number of species), abundance (number of individuals), and diversity (H'); ns = not sampled; SD = standard deviation.

Station	January	July
Species Richness		
SD7	9	16
SD8	10	14
SD10	13	17
SD12	9	17
SD13	7	15
SD14	8	11
Survey Mean	9	15
Survey SD	2	2
Abundance		
SD7	1351	2654
SD8	1116	1438
SD10	2528	2340
SD12	3447	1066
SD13	1117	966
SD14	719	820
Survey Mean	1713	1547
Survey SD	1049	770
Diversity		
SD7	0.2	0.2
SD8	0.1	0.2
SD10	0.1	0.2
SD12	0.3	0.9
SD13	0.3	1.1
SD14	0.6	1.1
Survey Mean	0.2	0.6
Survey SD	0.2	0.5

insight into spatial and temporal variability of demersal fish populations across the PLOO region. Pacific sanddabs continued to dominate fish assemblages during 2010 as they have for many years, and accounted for 42% of the total fish catch. Other characteristic, but less abundant species of fish that occurred at >75% of sites included California lizardfish, halfbanded rockfish, longspine combfish, plainfin midshipman, pink seaperch, yellowchin sculpin, Dover sole, stripetail rockfish, shortspine combfish, English sole, greenstriped rockfish, and bigmouth sole. The majority of individuals surveyed continued to be relatively small in size, and averaged less than 20 cm in length. Spatial analysis found that abundance of many fish species was greater at northern farfield stations (~8 km north of the PLOO) than at southern farfield stations (9 km south of the PLOO). The lack of significant differences between fish abundances from nearfield sites to any of the farfield sites suggests that the PLOO is not affecting demersal fish abundances. Similarly, although a significant temporal difference in fish abundances was detected, the years where changes occurred were not related to the onset of PLOO wastewater discharge, and are instead indicative of natural, large-scale oceanographic processes.

As in previous years, assemblages of megabenthic invertebrates in the region were dominated by the sea urchin *Lytechinus pictus*. Variation in overall community structure of trawl-caught invertebrates generally reflects changes in the abundance of this species, although other species such as the brittle star *Ophiura luetkenii*, the sea pen *Acanthoptilum* sp, the sea slug *Pleurobranchaea californica*, the sea cucumber *Parastichopus californicus,* the sea stars *Astropecten verrilli* and *Luidia foliolata,* and the octopus *Octopus rubescens* also contributed to some community differences.

Overall, results of the 2010 trawl surveys provide no evidence that wastewater discharged through the PLOO has affected either demersal fish or megabenthic invertebrate communities in the region. Although highly variable, no significant differences in the abundance and distribution of trawl-caught fishes were found between stations located near the outfall when compared to sites located farther away. Additionally, no patterns among invertebrate species assemblages relating to the PLOO were detectable. These results are supported by the findings of another recent assessment of these communities off San Diego (City of San Diego 2007). Significant changes in these communities appear most likely to be due to natural factors such as change in ocean water temperatures associated with large-scale oceanographic events or to the mobile nature of many of resident species. Finally, the absence of

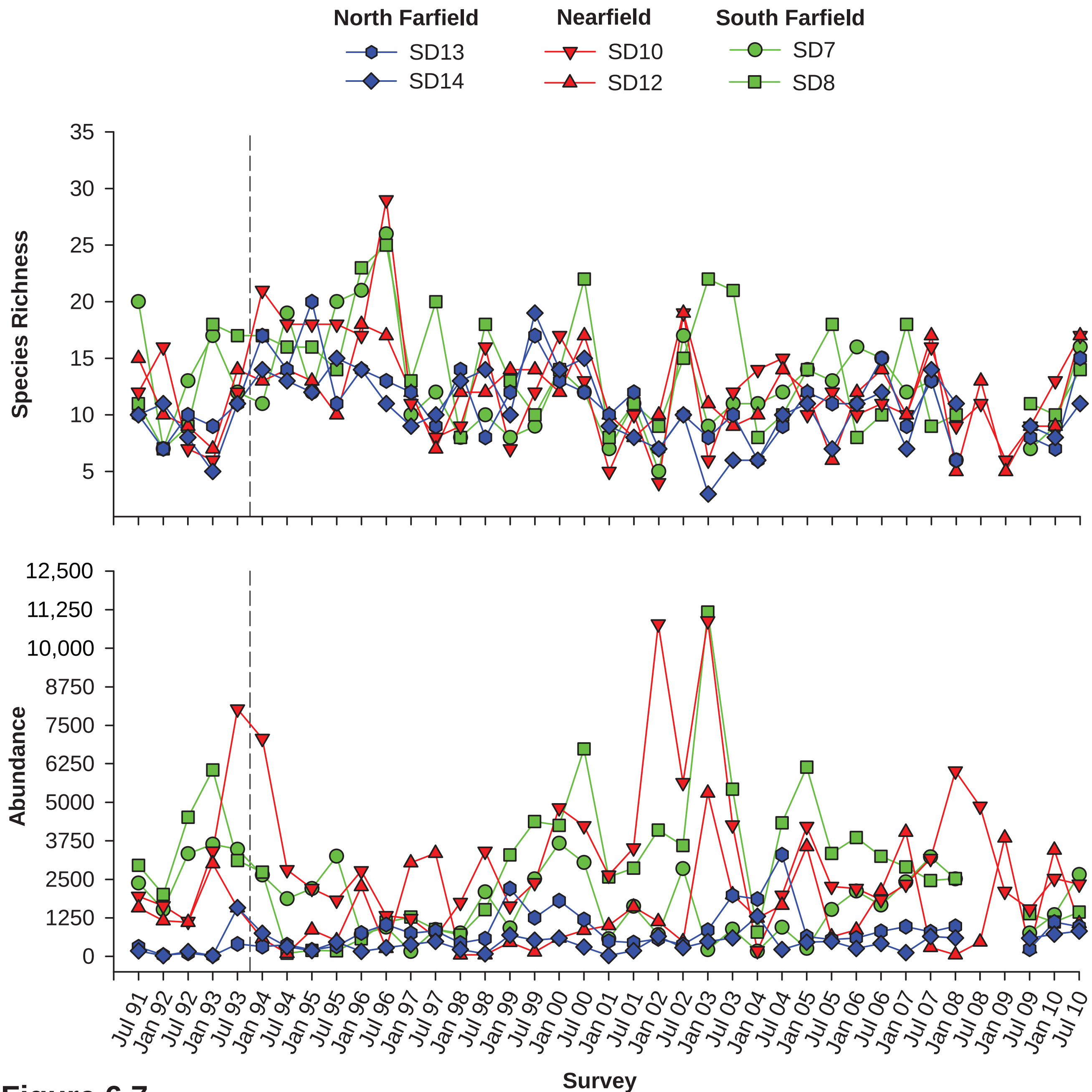


Figure 6.7

Species richness and abundance of megabenthic invertebrates collected at each trawl station between 1991 and 2010. Data are total number of species and total number of individuals per haul, respectively. Dashed line represents initiation of wastewater discharge. Only stations SD10 and SD12 were sampled during July 2008 and January 2009 due to a Bight'08 resource exchange.

disease or other physical abnormalities in local fishes suggests that their populations continue to be healthy off Point Loma.

Literature Cited

Allen, M.J., S.L. Moore, K.C. Schiff, S.B. Weisberg, D. Diener, J.K. Stull, A. Groce, J. Mubarak, C.L. Tang, and R. Gartman. (1998). Southern California Bight 1994 Pilot Project: V. Demersal Fishes and Megabenthic Invertebrates. Southern California Coastal Water Research Project, Westminster, CA.

Allen, M.J. (2005). The check list of trawl-caught fishes for Southern California from depths of 2–1000 m. Southern California Coastal Water Research Project, Westminster, CA.

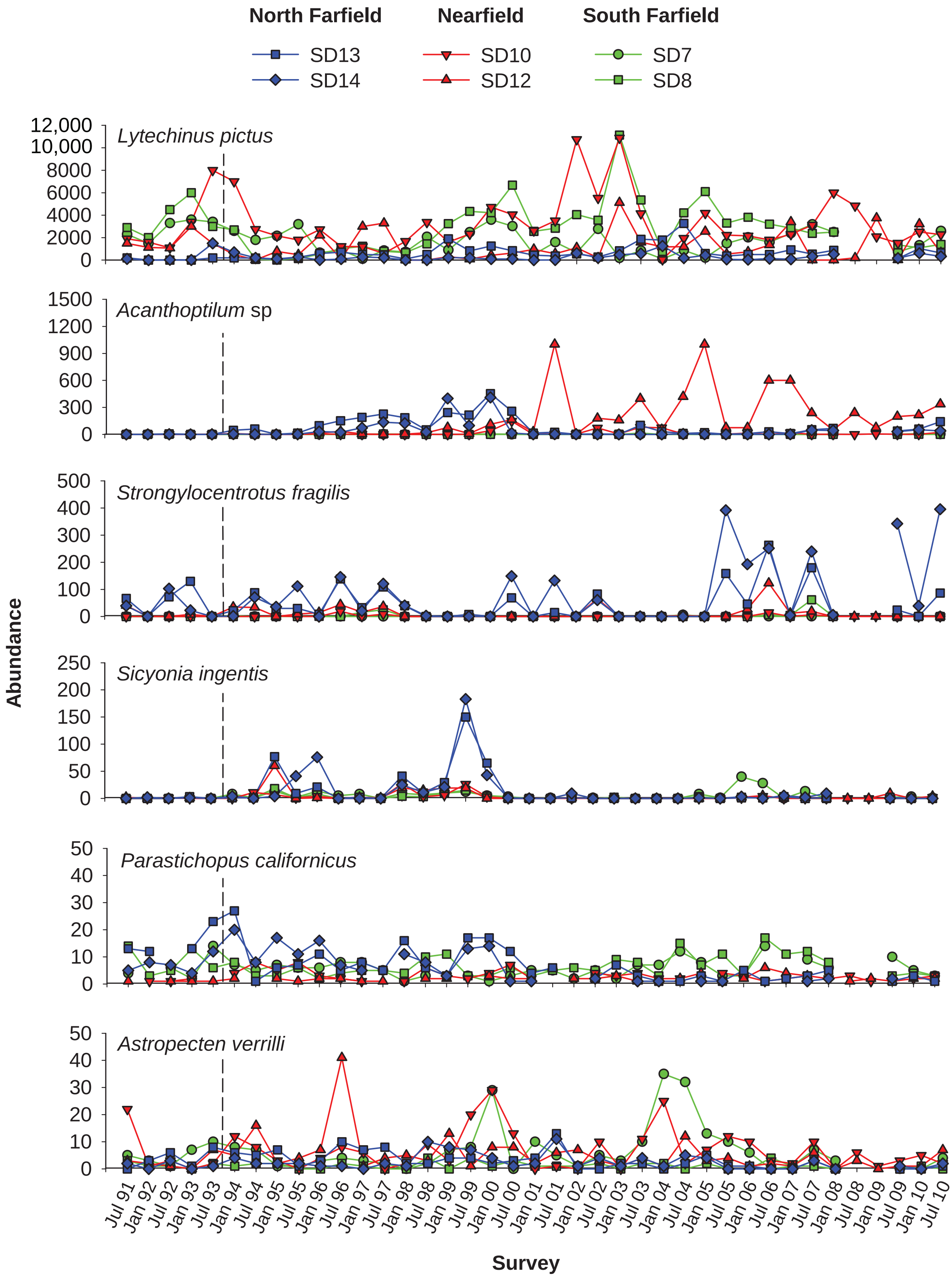


Figure 6.8

The five most abundant megabenthic species collected in the PLOO region from 1991 through 2010. Data are total number of individuals per haul. Dashed line represents initiation of wastewater discharge. Only stations SD10 and SD12 were sampled during July 2008 and January 2009 due to a Bight'08 resource exchange.

Brusca, R.C. (1978). Studies on the cymothoid fish symbionts of the eastern Pacific (Crustacea: Cymothoidae). II. Systematics and biology of *Livoneca vulgaris* Stimpson 1857. Occasional Papers of the Allan Hancock Foundation. (New Series), 2: 1–19.

Brusca, R.C. (1981). A monograph on the Isopoda Cymothoidae (Crustacea) of the eastern Pacific. Zoological Journal of the Linnean Society, 73: 117–199.

City of San Diego. (2007). Appendix E. Benthic Sediments and Organisms. In: Application for Renewal of NPDES CA0107409 and 301(h) Modified Secondary Treatment Requirements, Point Loma Ocean Outfall. Volume IV, Appendices A thru F. Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Clarke, K.R. (1993). Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology, 18: 117–143.

Clarke, K.R. and R.N. Gorley. (2006). Primer v6: User Manual/Tutorial. PRIMER-E: Plymouth.

Clarke, K.R., P.J. Somerfield, and R.N. Gorley. (2008). Testing of null hypotheses in exploratory community analyses: similarity profiles and biota-environment linkage. Journal of Experimental Marine Biology and Ecology, 366: 56–69.

Cross, J.N., J.N. Roney, and G.S. Kleppel. (1985). Fish food habitats along a pollution gradient. California Fish and Game, 71: 28–39.

Cross, J.N. and L.G. Allen. (1993). Chapter 9. Fishes. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. p 459–540.

Eschmeyer, W.N. and E.S. Herald. (1998). A Field Guide to Pacific Coast Fishes of North America. Houghton and Mifflin Company, New York.

Helvey, M. and R.W. Smith. (1985). Influence of habitat structure on the fish assemblages associated with two cooling-water intake structures in southern California. Bulletin of Marine Science, 37: 189–199.

Karinen, J.B., B.L. Wing, and R.R. Straty. (1985). Records and sightings of fish and invertebrates in the eastern Gulf of Alaska and oceanic phenomena related to the 1983 El Niño event. In: W.S. Wooster and D.L. Fluharty (eds.). El Niño North: El Niño Effects in the Eastern Subarctic Pacific Ocean. Washington Sea Grant Program. p 253–267.

Murawski, S.A. (1993). Climate change and marine fish distribution: forecasting from historical analogy. Transactions of the American Fisheries Society, 122: 647–658.

Warwick, R.M. (1993). Environmental impact studies on marine communities: pragmatical considerations. Australian Journal of Ecology, 18: 63–80.

This page intentionally left blank

Chapter 7
Bioaccumulation of Contaminants in Fish Tissues

Chapter 7. Bioaccumulation of Contaminants in Fish Tissues

Introduction

Bottom dwelling (i.e., demersal) fishes are collected as part of the Point Loma Ocean Outfall (PLOO) monitoring program to assess the accumulation of contaminants in their tissues. Anthropogenic inputs to coastal waters (including municipal wastewater outfalls) can lead to increased concentrations of chemical contaminants within the local marine environment, which can in turn bioaccumulate in the tissues of fishes and their prey. This is because the accumulation of contaminants in most fishes occurs through the biological uptake of dissolved chemicals from seawater and the ingestion and assimilation of pollutants contained in different food sources (Rand 1995, USEPA 2000). In addition, demersal fishes may accumulate contaminants through ingestion of suspended particulates or sediments that contain pollutants because of their proximity to seafloor sediments. For this reason, the levels of many contaminants in the tissues of demersal fishes are often related to those found in the environment (Schiff and Allen 1997), thus making these types of assessments useful in biomonitoring programs.

The bioaccumulation portion of the Point Loma ocean monitoring program consists of two components: (1) liver tissues analyzed for trawl-caught fishes; (2) muscle tissues analyzed for fishes collected by hook and line (rig fishing). Species of fish collected by trawling activities (see Chapter 6) are considered representative of the general demersal fish community, with certain species targeted (e.g., Pacific sanddabs) based on their overall prevalence and ecological significance. The chemical analysis of liver tissues in these trawl-caught fishes is especially important for assessing population effects because this organ is where contaminants typically concentrate (i.e., bioaccumulate). In contrast, fishes targeted for capture by rig fishing represent species that are characteristic of a typical sport fisher's catch (e.g., various species of rockfish), and are therefore considered of recreational and commercial importance and more directly relevant to human health concerns. Consequently, muscle tissue is analyzed from these fishes because it is the tissue most often consumed by humans, and therefore the results may have public health implications. All liver and muscle tissue samples collected are chemically analyzed for contaminants as specified in the NPDES discharge permits that govern the PLOO monitoring program (see Chapter 1). Most of these contaminants are also sampled for the National Status and Trends Program, which was initiated by the National Oceanic and Atmospheric Administration (NOAA) to detect and monitor changes in the environmental quality of the nation's estuarine and coastal waters by tracking contaminants thought to be of environmental concern (Lauenstein and Cantillo 1993).

This chapter presents the results of all chemical analyses that were performed on the tissues of fishes collected in the PLOO region during 2010. The goals of the chapter are to: (1) assess the level of contaminant loading in fishes throughout the region, (2) identify possible effects of wastewater discharge on contaminant accumulation in fishes collected near the discharge site, and (3) identify any spatial or temporal trends in contaminant loading.

Materials and Methods

Field Collection

Fishes were collected during October 2010 from four trawl zones and two rig fishing stations (Figure 7.1). Each trawl zone represents an area centered around one or two specific trawl stations as specified in Chapter 6. Zone 1 includes the nearfield area within a 1-km radius of stations SD10 and SD12 located just south and north of the PLOO, respectively. Zone 2 includes the area within a 1-km radius surrounding northern farfield stations SD13 and SD14. Zone 3 represents the area within a 1-km radius surrounding farfield station

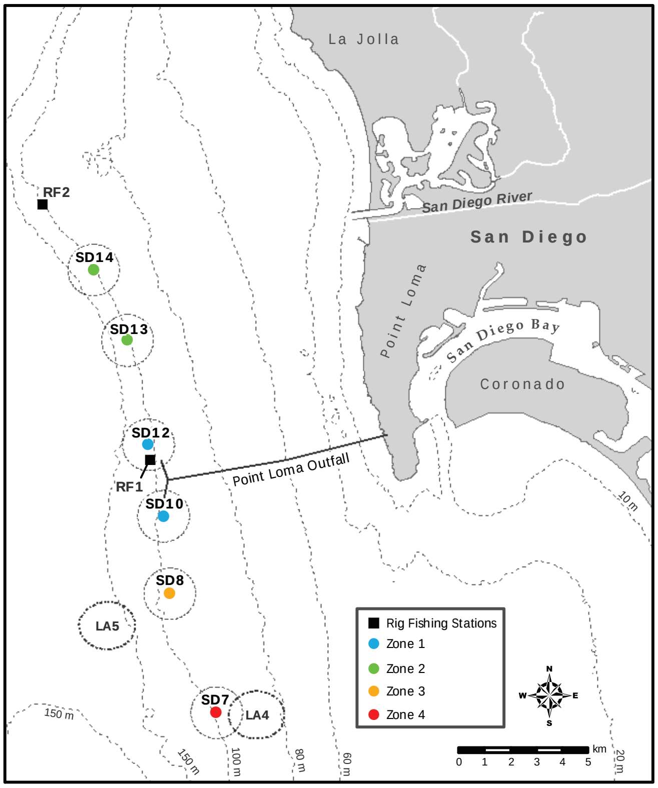


Figure 7.1
Otter trawl stations/zones and rig fishing stations for the Point Loma Ocean Outfall Monitoring Program. See text for description of zones.

SD8, which is located south of the outfall near the LA-5 dredged material disposal site. Zone 4 is the area within a 1-km radius surrounding farfield station SD7 located several kilometers south of the outfall near the non-active LA-4 disposal site. All trawl-caught fishes were collected following City of San Diego guidelines (see Chapter 6 for a description of collection methods). Efforts to collect targeted fish species at the trawl stations were limited to five 10-minute (bottom time) trawls per zone. Fishes collected at the two rig fishing stations were caught within 1 km of the station coordinates using standard rod and reel procedures. Station RF1 is located within 1 km of the outfall and is considered the nearfield site. In contrast, station RF2 is located about 11 km northwest of the outfall and is considered farfield for the analyses herein. Fishing effort was limited to 5 hours at each station.

Pacific sanddabs (*Citharichthys sordidus*) were collected for analysis of liver tissues from the trawling zones, while California scorpionfish (*Scorpaena guttata*), and several different species of rockfish (*Sebastes*) were collected for analysis of muscle tissues at the rig fishing stations (Table 7.1). Five different species of rockfish were analyzed, including copper rockfish (*S. caurinus*), chilipepper rockfish (*S. goodei*), flag rockfish (*S. rubrivinctus*), greenspotted rockfish (*S. chilorostictus*), and vermilion rockfish (*S. miniatus*).

In order to facilitate collection of sufficient amounts of tissue for subsequent chemical analysis, only fishes ≥13 cm in standard length were retained. These fishes were sorted into three composite samples per zone/station, with each composite containing a minimum of three individuals. Composite samples were typically made up of tissues from a single species; the only exceptions were two samples that consisted of mixed species of rockfish from station RF2 (Table 7.1). All fishes collected were wrapped in aluminum foil, labeled, sealed in re-sealable plastic bags, placed on dry ice, and transported to the City's Marine Biology Laboratory where they were held in the freezer at -80°C until dissection and tissue processing.

Tissue Processing and Chemical Analyses

All dissections were performed according to standard techniques for tissue analysis. A brief summary follows, but see City of San Diego (2004) for additional details. Prior to dissection, each fish was partially defrosted and then cleaned with a paper towel to remove loose scales and excess mucus. The standard length (cm) and weight (g) of each fish were recorded (Appendix F.1). Dissections were carried out on Teflon® pads that were cleaned between samples. The liver or muscle tissues from each dissected fish were then placed in separate glass jars for each composite sample, sealed, labeled, and stored in a freezer at -20°C prior to chemical analyses. All samples were subsequently delivered to the City's Wastewater Chemistry Services Laboratory for analysis within 10 days of dissection.

Chemical constituents were measured on a wet weight basis, and included trace metals, DDT and other chlorinated pesticides, and polychlorinated

Table 7.1

Species of fish collected from each PLOO trawl zone or rig fishing station (RF1–RF2) during October 2010. Comp = composite; PS = Pacific sanddab; CSF = California scorpionfish; VRF = vermilion rockfish; MRF = mixed rockfish.

Station/Zone	Comp 1	Comp 2	Comp3
Zone 1	PS	PS	PS
Zone 2	PS	PS	PS
Zone 3	PS	PS	PS
Zone 4	PS	PS	PS
RF1	CSF	CSF	CSF
RF2	VRF	MRF[a]	MRF[b]

[a] Includes copper, chillipepper, and greenspotted rockfish
[b] Includes vermilion and flag rockfish

biphenyl compounds (PCBs) (see Appendix F.2 for full listing and chemical abbreviations). Metal concentrations were measured in units of mg/kg and are expressed herein as parts per million (ppm), while pesticides and PCBs were measured as µg/kg and expressed as parts per billion (ppb). The data for each parameter reported herein were generally limited to values above method detection limits (MDL). However, concentrations below MDLs were included as estimated values if the presence of the specific constituent was verified by mass-spectrometry (i.e., spectral peaks confirmed). A more detailed description of the analytical protocols is provided by the Wastewater Chemistry Services Laboratory (City of San Diego 2011a).

Data Analyses

Data summaries for each contaminant include detection rates (i.e., number of reported values/ number of samples), and the minimum, maximum, and mean detected values of each parameter by species. Totals for DDT and PCBs were calculated for each sample as the sum of the detected constituents. For example, total DDT (tDDT) equals the sum of all DDT derivatives, while total PCB (tPCB) equals the sum of all individual congeners. The detected values for each of these individual constituents are listed in Appendix F.3. In addition, the distribution of frequently detected contaminants in fishes collected in the PLOO region was assessed by comparing concentrations in fishes collected at the "nearfield" zone and station (zone 1, RF1) to those from "farfield" stations located farther away to the south (zones 3 and 4) and north (zone 2, RF2). Because concentrations of contaminants can vary so much among different species of fish, only intra-species comparisons were used for these evaluations. Finally, in order to address seafood safety and public health issues, the concentrations of contaminants found in fish muscle tissue samples collected in 2010 were compared to state, national, and international limits and standards. These include: (1) the California Office of Environmental Health Hazard Assessment (OEHHA), which has developed fish contaminant goals for chlordane, DDT, methylmercury, selenium, and PCBs (Klasing and Brodberg 2008); (2) the United States Food and Drug Administration (USFDA), which has set limits on the amount of mercury, total DDT, and chlordane in seafood that is to be sold for human consumption (Mearns et al. 1991); (3) international standards for acceptable concentrations of various metals and DDT (Mearns et al. 1991).

Results

Contaminants in Trawl-Caught Fishes

Metals

Eight metals were detected in 100% of the liver tissue samples analyzed from trawl-caught Pacific sanddabs in the PLOO region during 2010, including arsenic, cadmium, copper, iron, manganese, mercury, selenium and zinc (Table 7.2). Another seven metals were detected less frequently in fewer than 83% of the samples. These included aluminum, barium, chromium, nickel, silver, thallium and tin. Antimony, beryllium and lead were not detected in any of the liver samples collected during the year. Most metals occurred at concentrations ≤20 ppm. Exceptions included higher levels up to about 83 ppm for iron and 35 ppm for zinc. Comparisons of metal concentrations in tissue samples collected from fish at the nearfield (zone 1) stations to those located farther away in zones 2–4 revealed no clear pattern between contaminant loads in local fishes and proximity to the PLOO (Figure 7.2). Only concentrations of tin appeared to be higher in sanddab livers collected near the outfall than at the other monitoring sites, although even these higher levels were very low when compared to values reported previously for the region (City of San Diego 2009).

Pesticides

Only three chlorinated pesticides (i.e., heptachlor, HCB, and DDT) were detected in trawl-caught Pacific sanddabs during 2010 (Table 7.2). Heptachlor was detected in a single liver sample from zone 2 at a concentration of 25 ppb. Both HCB and DDT were detected in most or all tissue samples (≥92%) but at concentrations substantially lower than historical maxima (City of San Diego 2007). For example, tDDT was present in fish tissues at levels ranging between 90.1–177.5 ppb, while HCB concentrations were lower with a maximum of 8 ppb. Total DDT was composed primarily of p,p-DDE, which accounted for up to 81% of this pesticide in each sample (Appendix F.3). Another two DDT derivatives, p,p-DDMU and p,p-DDT, occurred in every sanddab liver sample in 2010, whereas p,p-DDD and o,p-DDE were detected less frequently. All four of these DDT derivatives were found at concentrations ≤42 ppb. Concentrations of HCB and DDT in fish tissues were similar between the nearfield zone and farfield zones (Figure 7.3).

PCBs

PCBs occurred in all liver tissue samples analyzed during 2010 (Table 7.2). Seven of the nineteen PCB congeners that were detected occurred in 100% of the samples; these included PCB 99, PCB 110, PCB 118, PCB 138, PCB 153/168, PCB 180, and PCB 187 (Appendix F.3). Of these, PCB 153/168 and PCB 138 occurred at the highest concentrations, with values ranging up to 63 and 34 ppb, respectively. Total PCB concentrations were variable, ranging between about 47–280 ppb (Table 7.2). The highest PCB concentrations occurred in fish from nearfield zone 1 and farfield zones 3 (near LA-5) and 4 (near LA-4) (Figure 7.3). Overall, concentrations of tPCB in samples from all zones were an order of magnitude less than reported previously for the region (City of San Diego 2007).

Table 7.2

Summary of metals, pesticides, total PCBs, and lipids in liver tissues of Pacific sanddabs collected at PLOO trawl zones during 2010. Data include detection rate (DR), minimum, maximum, and mean* detected concentrations ($n \leq 12$). See Appendix F.2 for MDLs and Appendix F.3 for values of individual constituents summed for total DDT and total PCB.

Parameter	DR (%)	Min	Max	Mean
Metals (ppm)				
Aluminum	58	nd	16.50	7.88
Antimony	0	nd	nd	—
Arsenic	100	2.18	4.08	2.95
Barium	75	nd	0.06	0.05
Beryllium	0	nd	nd	—
Cadmium	100	3.61	10.90	7.05
Chromium	83	nd	0.40	0.20
Copper	100	1.66	6.28	3.15
Iron	100	49.00	82.80	63.16
Lead	0	nd	nd	—
Mangenese	100	0.93	2.14	1.35
Mercury	100	0.04	0.12	0.06
Nickel	17	nd	0.28	0.25
Selenium	100	0.50	1.07	0.81
Silver	42	nd	0.19	0.11
Thallium	75	nd	0.96	0.60
Tin	50	nd	0.42	0.26
Zinc	100	17.60	35.10	24.72
Pesticides (ppb)				
HCB	92	nd	8.00	5.80
Heptachlor	8	nd	25.00	25.00
Total DDT	100	90.10	177.50	128.35
Total PCB (ppb)	100	46.70	280.30	194.86
Lipids (% weight)	100	9.26	39.70	28.39

nd = not detected

* Minimum and maximum values were calculated based on all samples, whereas means were calculated on detected values only.

Contaminants in Fishes Collected by Rig Fishing

Arsenic, copper, mercury, selenium and zinc occurred in 100% of the muscle tissue samples from fishes collected at the two rig fishing stations

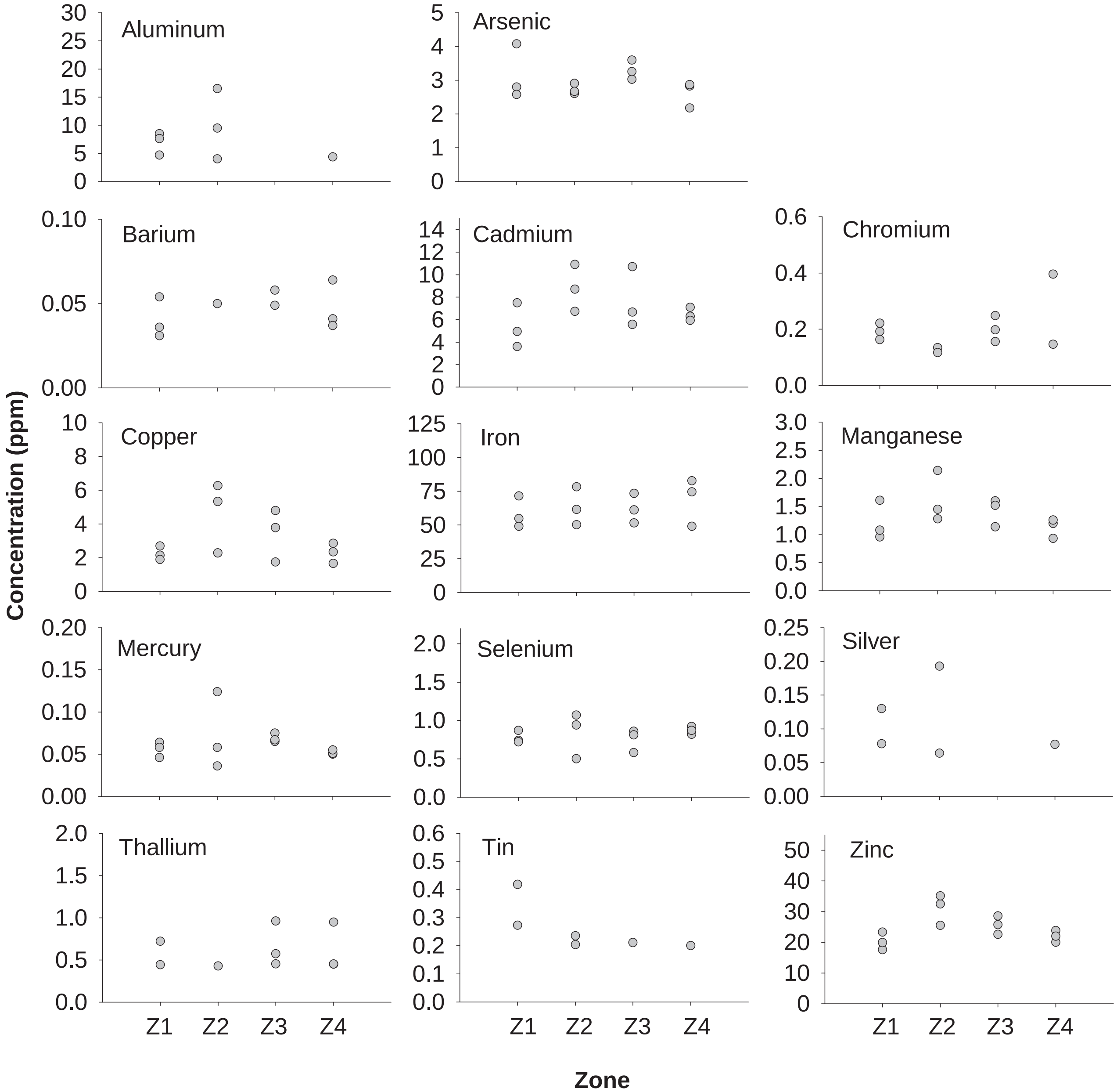


Figure 7.2
Concentrations of metals detected in at least 20% of liver tissue samples from Pacific sanddabs collected from each trawl zone (Z1–Z4) off Point Loma during 2010. Missing values = non-detects. Zone 1 is considered "nearfield".

in 2010 (Table 7.3). In addition to these five metals, aluminum, chromium, iron and thallium were detected, but in ≤50% of samples. The metals present in the highest concentrations were aluminum (up to about 3 ppm), arsenic (up to about 2 ppm), iron (up to about 4 ppm), and zinc (up to about 4 ppm). Concentrations of the remaining metals in fish muscle tissues were all less than 1 ppm. The highest concentrations of arsenic, chromium, mercury, thallium and zinc occurred in muscle tissues of California scorpionfish. In contrast, rockfish muscle tissues contained the highest concentrations of aluminum, copper, iron and selenium.

DDT and HCB were the only pesticides detected in rockfish muscle tissues collected in the Point Loma region during 2010 (Table 7.4). Total DDT (mostly p,p-DDE) was detected in 100% of the samples but at relatively low concentrations ≤10.3 ppb (Appendix F.3). The highest tDDT concentrations were detected in muscle tissue from a California scorpionfish. HCB was detected in 50% of the samples, including muscle tissues collected from California scorpionfish and rockfish, at low concentrations (0.3–0.4 ppb).

PCBs were detected in every muscle tissue sample collected at the two rig fishing stations in 2010, with tPCB concentrations ranging from 0.3 to 9.0 ppb (Table 7.4). PCB 153/168 was the most frequently detected congener, occurring in 100% of the samples (Appendix F.3). Other common congeners that were detected in at least 50% of the samples were PCB 118, PCB 138 and PCB 149. The highest concentration of PCBs was detected in muscle tissue from a California scorpionfish.

State, national, and/or international limits and standards exist for several metal (i.e., arsenic, chromium, copper, iron, mercury, selenium, thallium, zinc), DDT, and PCB concentrations in fish tissues (Tables 7.3, 7.4). Of those contaminants detected in fish muscle tissues off Point Loma during 2010, only arsenic and selenium occurred at concentrations higher than median international standards, while mercury (as a proxy for methylmercury) and tPCB exceeded state OEHHA fish contaminant goals. Levels of tDDT did not exceed either of these standards, and none of the contaminants evaluated exceeded USFDA action limits. Exceedances for mercury and selenium occurred in California scorpionfish and mixed rockfish samples, while exceedances for arsenic and tPCB occurred only in California scorpionfish samples.

In addition to addressing seafood safety and public health issues, spatial patterns were analyzed for tDDT and tPCB, as well as for all metals that occurred frequently in scorpionfish and rockfish muscle tissues (Figure 7.4). Overall, concentrations of tDDT, tPCB, and various metals in the muscles of fishes captured at the two rig fishing stations were fairly similar, which suggests that there was no relationship with proximity to the outfall. However, comparisons of contaminant loads in fishes from these stations should be considered with caution since different species were collected at the two sites, and the bioaccumulation of contaminants may differ between species because of differences in physiology, diet, migration habits, and/or other large scale movements that affect contaminant exposure and uptake. This problem may be minimal in the Point Loma region since all fish sampled in 2010 are bottom dwelling tertiary carnivores with similar life history characteristics.

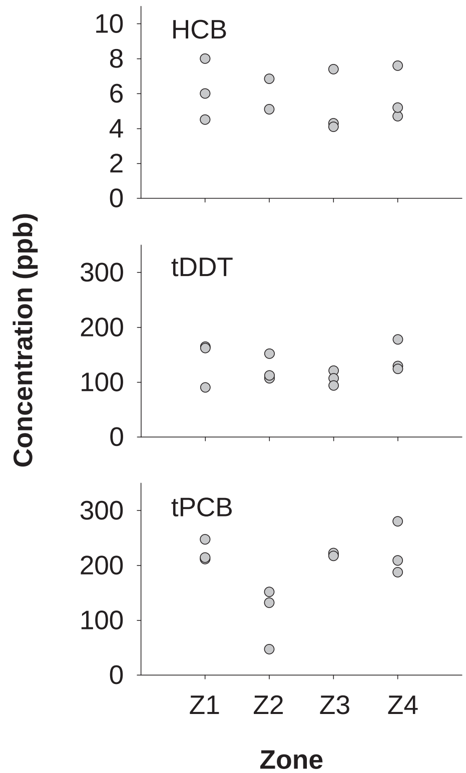


Figure 7.3
Concentrations of the most frequently detected pesticides (≥20% of samples) and tPCB in liver tissues of Pacific sanddabs collected from each PLOO trawl zone (Z1–Z4) during 2010. Missing values = non-detects. Zone 1 is considered "nearfield".

Discussion

Fishes are often highly mobile depending on species or life-history stage, and the area in which an individual is caught may only represent a tiny fraction of the geographic area in which it lives. For example, it has been previously reported that California scorpionfish tagged in Santa Monica Bay near Los Angeles have been recaptured as far south as the Coronado Islands in Mexico (Hartmann 1987, Love et al. 1987). Therefore, even though an individual fish may have

Table 7.3

Summary of metals in muscle tissues of fishes collected at PLOO rig fishing stations during 2010. Data include the number of detected values (*n*), minimum, maximum, and mean* detected concentrations per species, and the detection rate and maximum value for all species. Concentrations are expressed as parts per million (ppm). The number of samples per species is indicated in parentheses. Bold values meet or exceed OEHHA fish contaminant goals, USFDA action limits (AL), or median international standards (IS). See Appendix F.2 for names of each metal represented by periodic table symbol.

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
California scorpionfish																		
n (out of 3)	0	0	3	0	0	0	1	3	1	0	0	3	0	3	0	1	0	3
Min	nd	nd	1.06	nd	nd	nd	nd	0.21	nd	nd	nd	0.10	nd	0.27	nd	nd	nd	3.51
Max	nd	nd	**2.17**	nd	nd	nd	0.14	0.36	2.22	nd	nd	**0.34**	nd	**0.33**	nd	0.60	nd	3.92
Mean	–	–	**1.70**	–	–	–	0.14	0.29	2.22	–	–	0.18	–	**0.30**	–	0.60	–	3.78
Mixed rockfish																		
n (out of 2)	0	0	2	0	0	0	0	2	1	0	0	2	0	2	0	1	0	2
Min	nd	nd	0.74	nd	nd	nd	nd	0.35	nd	nd	nd	0.11	nd	0.29	nd	nd	nd	2.63
Max	nd	nd	1.18	nd	nd	nd	nd	0.42	3.64	nd	nd	**0.23**	nd	**0.46**	nd	0.47	nd	3.50
Mean	–	–	0.96	–	–	–	–	0.39	3.64	–	–	0.17	–	**0.37**	–	0.47	–	3.06
Vermilion rockfish																		
n (out of 1)	1	0	1	0	0	0	0	1	1	0	0	1	0	1	0	0	0	1
Min	3.1	nd	1.25	nd	nd	nd	nd	0.42	2.56	nd	nd	0.09	nd	0.23	nd	nd	nd	3.55
Max	3.1	nd	1.25	nd	nd	nd	nd	0.42	2.56	nd	nd	0.09	nd	0.23	nd	nd	nd	3.55
Mean	3.1	–	1.25	–	–	–	–	0.42	2.56	–	–	0.09	–	0.23	–	–	–	3.55
All Species:																		
Detection Rate (%)	17	0	100	0	0	0	17	100	50	0	0	100	0	100	0	33	0	100
Max	3.1	nd	**2.17**	nd	nd	nd	0.14	0.42	3.64	nd	nd	0.34	nd	0.46	nd	0.60	nd	3.92
OEHHA**	na	na	na	na	na	na	na	na	na	na	na	0.22	na	7.4	na	na	na	na
AL***	na	na	na	na	na	na	na	na	na	na	na	1.0	na	na	na	na	na	na
IS***	na	na	1.4	na	na	na	1	20	na	na	na	0.5	na	0.3	na	na	na	70

na = not available; nd = not detected

* Minimum and maximum values were calculated based on all samples, whereas means were calculated on detected values only.

** From the California OEHHA (Klasing and Brodberg 2008).

*** From Mearns et al. 1991. USFDA action limits for mercury and all international standards are for shellfish, but are often applied to fish.

Table 7.4

Summary of pesticides, tPCB, and lipids in muscle tissues of fishes collected at PLOO rig fishing stations during 2010. Data include number of detected values (*n*), minimum, maximum, and mean* detected concentrations per species, and the detection rate (DR) and maximum value for all species. The number of samples per species is indicated in parentheses. Bold values meet or exceed OEHHA fish contaminant goals, USFDA action limits (AL), or median international standards (IS). See Appendix F.2 for MDLs and Appendix F.3 for values of individual constituents summed for tDDT and tPCB.

	Pesticides			
	HCB (ppb)	tDDT (ppb)	tPCB (ppb)	Lipids (% weight)
California scorpionfish				
n (out of 3)	1	3	3	3
Min	nd	1.6	1.0	0.4
Max	0.4	10.3	**9.0**	0.6
Mean	0.4	4.5	**4.9**	0.5
Mixed rockfish				
n (out of 2)	1	2	2	2
Min	nd	1.8	0.3	0.9
Max	0.3	5.0	2.5	1.0
Mean	0.3	3.4	1.4	1.0
Vermilion rockfish				
n (out of 1)	1	1	1	1
Min	0.3	5.6	1.7	0.7
Max	0.3	5.6	1.7	0.7
Mean	0.3	5.6	1.7	0.7
All Species:				
DR (%)	50	100	100	100
Max	0.4	10.3	**9.0**	1.0
OEHHA**	na	21	3.6	na
AL***	na	5000	na	na
IS***	na	5000	na	na

na = not available; nd = not detected

* Minimum and maximum values were calculated based on all samples, whereas means were calculated on detected values only.

** From the California OEHHA (Klasing and Brodberg 2008).

*** From Mearns et al. 1991. USFDA action limits for mercury and all international standards are for shellfish, but are often applied to fish.

been caught near the Point Loma outfall or other areas off San Diego, any tissue contaminants it contains are likely bioaccumulated over a broad geographic area. It is therefore difficult to attribute the contaminant loading in liver or muscle tissues of fishes collected in the PLOO region to the discharge of wastewater from the outfall.

During 2010, several trace metals, pesticides and PCBs were detected in Pacific sanddab liver tissues samples collected in the PLOO region. Many of these contaminants were also detected in muscle tissues of California scorpionfish and several species of rockfish (*Sebastes*) sampled via rig fishing techniques, although often less frequently and/or in lower concentrations. Tissue contaminant loads varied widely in fishes collected within and among stations. However, all contaminant levels were within the range of values reported previously for Southern California Bight (SBC) fishes (Mearns et al. 1991, Allen et al. 1998). In addition, concentrations of these contaminants were generally similar to those reported previously for the Point Loma region (City of San Diego 2003, 2007), as well as for other long-term monitoring sites for the South Bay Ocean Outfall monitoring area (City of San Diego 2011b). Further, while some muscle tissue samples from sport fishes collected off Point Loma had arsenic and selenium concentrations above the median international standard for shellfish, and some exhibited mercury and PCB levels that exceeded OEHHA fish contaminant goals, concentrations of all contaminants were still below the USFDA consumption limits for humans.

The frequent occurrence of metals and chlorinated hydrocarbons in PLOO fish tissues are likely due to multiple factors. For instance, Mearns et al. (1991) described the distribution of several contaminants, including arsenic, mercury, DDT, and PCBs as being ubiquitous in southern California waters, and not unique to the PLOO region. In fact, many metals occur naturally in the environment, although little information is available on background levels in fish tissues. Brown et al. (1986) determined that no areas of the SBC are sufficiently free of chemical contaminants to be considered reference sites. This has been supported by more recent work examining PCBs and DDTs (Allen et al. 1998, 2002).

In addition to distributional differences of contaminants in the environment, physiological accumulation of these contaminants differ among

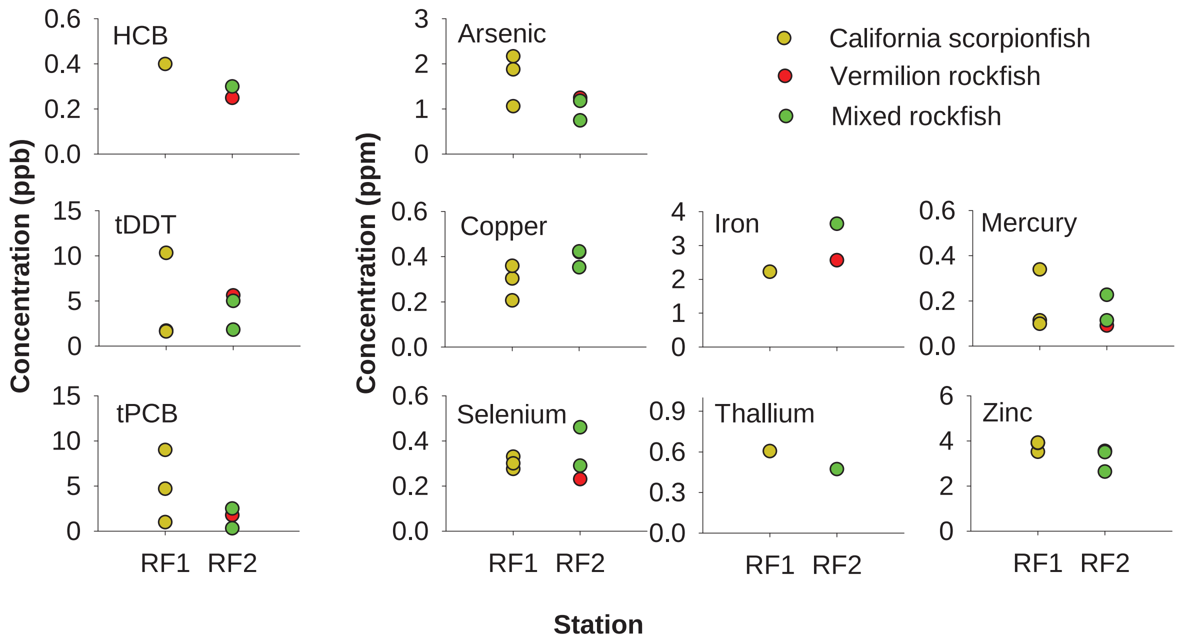


Figure 7.4
Concentrations of pesticides, tPCB, and metals detected in at least 20% of muscle tissue samples from fishes collected from each PLOO rig fishing station during 2010. Missing values = non-detects. Station RF1 is considered "nearfield".

species or even among individuals from different life history stages of a single species (see Groce 2002 and references therein). For example, different species exposed to the same concentrations of a contaminant often differ in the amount of the contaminant that ends up in their tissues. Finally, exposure to contaminants can vary greatly between different species and among individuals of the same species depending on migration habits (Otway 1991). For example, fishes may be exposed to contaminants in an area that is highly contaminated and then migrate into an area that is not.

Overall, there was no evidence that fishes collected in 2010 were contaminated by the discharge of wastewater from the PLOO. Concentrations of most contaminants were similar across zones or stations, and no relationship relevant to the outfall was evident. These results are consistent with findings of two recent assessments of bioaccumulation in fishes off San Diego (City of San Diego 2007, Parnell et al. 2008). Finally, there were no other indications of adverse fish health in the region, such as the presence of fin rot, other indicators of disease, or physical anomalies (see Chapter 6).

Literature Cited

Allen, M.J., S.L. Moore, K.C. Schiff, D. Diener, S.B. Weisberg, J.K. Stull, A. Groce, E. Zeng, J. Mubarak, C.L. Tang, R. Gartman, and C.I. Haydock. (1998). Assessment of demersal fish and megabenthic invertebrate assemblages on the mainland shelf of Southern California in 1994. Southern California Coastal Water Research Project, Westminster, CA.

Allen, M.J., A.K. Groce, D. Diener, J. Brown, S.A. Steinert, G. Deets, J.A. Noblet, S.L. Moore, D. Diehl, E.T. Jarvis, V. Raco-Rands, C. Thomas, Y. Ralph, R. Gartman, D. Cadien, S.B. Weisberg, and T. Mikel. (2002). Southern California Bight 1998 Regional Monitoring Program: V. Demersal Fishes and Megabenthic Invertebrates. Southern California Coastal Water Research Project, Westminster, CA.

Brown, D.A., R.W. Gossett, G.P. Hershelman, C.G. Word, A.M. Westcott, and J.N. Cross. (1986). Municipal wastewater contamination in the Southern California Bight: Part I — Metal and Organic Contaminants in Sediments and Organisms. Marine Environmental Research, 18: 291–310.

City of San Diego. (2003). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2002. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2004). Quality Assurance Manual, 2003. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2007). Appendix F. Bioaccumulation Assessment. In: Application for Renewal of NPDES CA0107409 and 301(h) Modified Secondary Treatment Requirements, Point Loma Ocean Outfall. Volume IV, Appendices A thru F. Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2009). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2008. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2011a). 2010 Annual Reports and Summary: Point Loma Wastewater Treatment Plant and Point Loma Ocean Outfall. City of San Diego, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2011b). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall, 2010. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Groce, A.K. (2002). Influence of life history and lipids on the bioaccumulation of organochlorines in demersal fishes. Master's thesis. San Diego State University. San Diego, CA.

Klasing, S. and R. Brodberg. (2008). Development of Fish Contaminant Goals and Advisory Tissue Levels for Common Contaminants in California Sport Fish: Chlordane, DDTs, Dieldrin, Methylmercury, PCBs, Selenium, and Toxaphene. California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, Sacramento, CA.

Hartmann, A.R. (1987). Movement of scorpionfishes (Scorpaenidae: *Sebastes* and *Scorpaena*) in the Southern California Bight. California Fish and Game, 73: 68–79.

Lauenstein, G.G. and A.Y. Cantillo, eds. (1993). Sampling and Analytical Methods of the NOAA National Status and Trends Program National Benthic Surveillance and Mussel Watch Projects 1984–1992: Vol. I–IV. Technical Memorandum. NOS ORCA 71. NOAA/NOS/ORCA, Silver Spring, MD.

Love, M.S., B. Axell, P. Morris, R. Collins, and A. Brooks. (1987). Life history and fishery of the California scorpionfish, *Scorpaena guttata*, within the Southern California Bight. Fisheries Bulletin, 85: 99–116.

Mearns, A.J., M. Matta, G. Shigenaka, D. MacDonald, M. Buchman, H. Harris, J. Golas, and G. Lauenstein. (1991). Contaminant Trends in the Southern California Bight: Inventory and Assessment. NOAA Technical Memorandum NOS ORCA 62. Seattle, WA.

Otway, N. (1991). Bioaccumulation studies on fish: choice of species, sampling designs, problems and implications for environmental management. In: A.G. Miskiewicz (ed.).

Proceedings of a Bioaccumulation Workshop: Assessment of the Distribution, Impacts, and Bioaccumulation of Contaminants in Aquatic Environments. Australian Marine Science Association, Inc./Water Board.

Parnell, P.E., A.K. Groce, T.D. Stebbins, and P.K. Dayton. (2008). Discriminating sources of PCB contamination in fish on the coastal shelf off San Diego, California (USA). Marine Pollution Bulletin, 56: 1992–2002.

Rand, G.M., ed. (1995). Fundamentals of Aquatic Toxicology: Effects, Environmental Fate, and Risk Assessment. 2nd ed. Taylor and Francis, Washington, D.C.

Schiff, K. and M.J. Allen. (1997). Bioaccumulation of chlorinated hydrocarbons in livers of flatfishes from the Southern California Bight. In: S.B. Weisberg, C. Francisco, and D. Hallock (eds.). Southern California Coastal Water Research Project Annual Report 1995–1996. Southern California Coastal Water Research Project, Westminster, CA.

[USEPA] United States Environmental Protection Agency. (2000). Bioaccumulation Testing and Interpretation for the Purpose of Sediment Quality Assessment. Status and Needs. EPA-823-R-00-001. U.S. Environmental Protection Agency. February 2000.

This page intentionally left blank

Glossary

Glossary

Absorption
The movement of dissolved substances (e.g., pollution) into cells by diffusion.

Adsorption
The adhesion of dissolved substances to the surface of sediment or on the surface of an organism (e.g., a flatfish).

Anthropogenic
Made and introduced into the environment by humans, especially pertaining to pollutants.

Assemblage
An association of interacting populations in a given habitat (e.g., an assemblage of benthic invertebrates on the ocean floor).

BACIP Analysis
An analytical tool used to assess environmental changes caused by the effects of pollution. A statistical test is applied to data from matching pairs of control and impacted sites before and after an event (i.e., initiation of wastewater discharge) to test for significant change. Significant differences are generally interpreted as being the result of the environmental change attributed to the event. Variation that is not significant reflects natural variation.

Benthic
Pertaining to the environment inhabited by organisms living on or in the ocean bottom.

Benthos
Living organisms (e.g., algae and animals) associated with the sea bottom.

Bioaccumulation
The process by which a chemical becomes accumulated in tissue over time through direct intake of contaminated water, the consumption of contaminated prey, or absorption through the skin or gills.

Biota
The living organisms within a habitat or region.

BOD
Biochemical oxygen demand (BOD) is the amount of oxygen consumed (through biological or chemical processes) during the decomposition of organic material contained in a water or sediment sample. It is a measure for certain types of organic pollution, such that high BOD levels suggest elevated levels of organic pollution.

BRI
The benthic response index (BRI) measures levels of environmental disturbance by assessing the condition of a benthic assemblage. The index was based on organisms found in the soft sediments of the Southern California Bight (SCB).

CFU
The colony-forming unit (CFU) is the bacterial cell or group of cells which reproduce on a plate and result in a visible colony that can be quantified as a measurement of density; it is often used to estimate bacteria concentrations in ocean water.

Control site
A geographic location that is far enough from a known pollution source (e.g., ocean outfall) to be considered representative of an undisturbed environment. Data collected from control sites are used as a reference and compared to impacted sites.

COP
The California Ocean Plan (COP) is California's ocean water quality control plan. It limits wastewater discharge and implements ocean monitoring. Federal law requires the plan to be reviewed every three years.

Crustacea
A group (subphylum) of marine invertebrates characterized by jointed legs and an exoskeleton (e.g., crabs, shrimp, and lobster).

CTD
A device consisting of a group of sensors that continually measure various physical and chemical properties such as conductivity (a proxy for salinity), temperature, and pressure (a proxy for depth) as it is lowered through the water. These parameters are used to assess the physical ocean environment.

Demersal
Organisms living on or near the bottom of the ocean and capable of active swimming.

Dendrogram
A tree-like diagram used to represent hierarchal relationships from a multivariate analysis where results from several monitoring parameters are compared among sites.

Detritus
Particles of organic material from decomposing organisms. Used as an important source of nutrients in a food web.

Diversity
A measurement of community structure which describes the abundances of different species within a community, taking into account their relative rarity or commonness.

Dominance
A measurement of community structure that describes the minimum number of species accounting for 75% of the abundance in each grab.

Echinodermata
A group (phylum) of marine invertebrates characterized by the presence of spines, a radially symmetrical body, and tube feet (e.g., sea stars, sea urchins, and sea cucumbers).

Effluent
Wastewater that flows out of a sewer, treatment plant outfall, or other point source and is discharged into a water body (e.g. ocean, river).

FIB
Fecal indicator bacteria (FIB) are the bacteria (total coliform, fecal coliform, and enterococcus) measured and evaluated to provide information about the movement and dispersion of wastewater discharged to the Pacific Ocean through the outfall.

Halocline
A vertical zone of water in which the salinity changes rapidly with depth.

Impact site
A geographic location that has been altered by the effects of a pollution source, such as a wastewater outfall.

Indicator species
Marine invertebrates whose presence in the community reflects the health of the environment. The loss of pollution-sensitive species or the introduction of pollution-tolerant species can indicate anthropogenic impact.

Infauna
Animals living in the soft bottom sediments usually burrowing or building tubes within.

Invertebrate
An animal without a backbone (e.g., sea star, crab, and worm).

Kurtosis
A measure that describes the shape (i.e., peakedness or flatness) of distribution relative to a normal distribution (bell shape) curve. Kurtosis can indicate the range of a data set, and is used herein to describe the distribution of particle sizes within sediment samples.

Macrobenthic invertebrate
Epifaunal or infaunal benthic invertebrates that are visible with the naked eye. This group typically includes those animals larger than meiofauna and smaller than megafauna. These animals are collected in grab samples from soft-bottom marine habitats and retained on a 1-mm mesh screen.

MDL
The EPA defines MDL (method detection limit) as “the minimum concentration that can be determined

with 99% confidence that the true concentration is greater than zero."

Megabenthic invertebrate
A larger, usually epibenthic and motile, bottom-dwelling animal such as a sea urchin, crab, or snail. These animals are typically collected by otter trawl nets with a minimum mesh size of 1 cm.

Mollusca
A taxonomic group (phylum) of invertebrates characterized as having a muscular foot, visceral mass, and a shell. Examples include snails, clams, and octupuses.

Motile
Self-propelled or actively moving.

Niskin bottle
A long plastic tube allowing seawater to pass through until the caps at both ends are triggered to close from the surface. They often are arrayed with several others in a rosette sampler to collect water at various depths.

Non-point source
Pollution sources from numerous points, not a specific outlet, generally carried into the ocean by storm water runoff.

NPDES
The National Pollutant Discharge Elimination System (NPDES) is a federal permit program that controls water pollution by regulating point sources that discharge pollutants into waters of the United States.

Ophiuroidea
A taxonomic group (class) of echinoderms that comprises the brittle stars. Brittle stars usually have five long, flexible arms and a central disk-shaped body.

PAHs
The USGS defines polycyclic aromatic hydrocarbons (PAHs) as, "hydrocarbon compounds with multiple benzene rings. PAHs are typical components of asphalts, fuels, oils, and greases."

PCBs
The EPA defines polychlorinated biphenyls (PCBs) as, "a category, or family, of chemical compounds formed by the addition of chlorine (C_{l2}) to biphenyl ($C_{12}H_{10}$), which is a dual-ring structure comprising two 6-carbon benzene rings linked by a single carbon-carbon bond."

PCB Congeners
The EPA defines a PCB congener as, "one of the 209 different PCB compounds. A congener may have between one and 10 chlorine atoms, which may be located at various positions on the PCB molecule."

Phi
The conventional unit of sediment size based on the log of sediment grain diameter. The larger the phi number, the smaller the grain size.

Plankton
Animal and plant-like organisms, usually microscopic, that are passively carried by ocean currents.

PLOO
The Point Loma Ocean Outfall (PLOO) is the underwater pipe originating at the Point Loma Wastewater Treatment Plant and used to discharge treated wastewater. It extends 7.2 km (4.5 miles) offshore and discharges into 96 m (320 ft) of water.

Point source
Pollution discharged from a single source (e.g., municipal wastewater treatment plant, storm drain) to a specific location through a pipe or outfall.

Polychaeta
A taxonomic group (class) of invertebrates characterized as having worm-like features, segments, and bristles or tiny hairs. Examples include bristle worms and tube worms.

Pycnocline
A depth zone in the ocean where sea water density changes rapidly with depth and typically is associated with a decline in temperature and increase in salinity.

Recruitment
The retention of young individuals into the adult population in an open ocean environment.

Relict sand
Coarse reddish-brown sand that is a remnant of a pre-existing formation after other parts have disappeared. Typically originating from land and transported to the ocean bottom through erosional processes.

Rosette sampler
A device consisting of a round metal frame housing a CTD in the center and multiple bottles (see Niskin bottle) arrayed about the perimeter. As the instrument is lowered through the water column, continuous measurements of various physical and chemical parameters are recorded by the CTD. Discrete water samples are captured at desired depths by the bottles.

SBOO
The South Bay Ocean Outfall (SBOO) is the underwater pipe originating at the International Wastewater Treatment Plant and used to discharge treated wastewater. It extends 5.6 km (3.5 miles) offshore and discharges into about 27 m (90 ft) of water.

SBWRP
The South Bay Water Reclamation Plant (SBWRP) provides local wastewater treatment services and reclaimed water to the South Bay. The plant began operation in 2002 and has a wastewater treatment capacity of 15 million gallons a day.

SCB
The Southern California Bight (SCB) is the geographic region that stretches from Point Conception, U.S.A. to Cabo Colnett, Mexico and encompasses nearly 80,000 km^2 of coastal land and sea.

Shell hash
Sediments composed of shell fragments.

Skewness
A measure of the lack of symmetry in a distribution or data set. Skewness can indicate where most of the data lies within a distribution. It can be used to describe the distribution of particle sizes within sediment grain size samples.

Sorting
The range of grain sizes that comprises marine sediments. Also refers to the process by which sediments of similar size are naturally segregated during transport and deposition according to the velocity and transporting medium. Well sorted sediments are of similar size (such as desert sand), while poorly sorted sediments have a wide range of grain sizes (as in a glacial till).

Species richness
The number of species per sample or unit area. A metric used to evaluate the health of macrobenthic communities.

Standard length
The measurement of a fish from the most forward tip of the body to the base of the tail (excluding the tail fin rays). Fin rays can sometimes be eroded by pollution or preservation so measurement that includes them (i.e., total length) is considered less reliable.

Thermocline
The zone in a thermally stratified body of water that separates warmer surface water from colder deep water. At a thermocline, temperature changes rapidly over a short depth.

Tissue burden
The total amount of measured chemicals that are present in the tissue (e.g. fish muscle).

Transmissivity
A measure of water clarity based upon the ability of water to transmit light along a straight path. Light that is scattered or absorbed by particulates (e.g., plankton, suspended solid materials) decreases the transmissivity (or clarity) of the water.

Upwelling
The movement of nutrient-rich and typically cold water from the depths of the ocean to the surface waters.

USGS
The United States Geological Survey (USGS) provides geologic, topographic, and hydrologic information on water, biological, energy, and mineral resources.

Van Dorn bottle
A water sampling device made of a plastic tube open at both ends that allows water to flow through. Rubber caps at the tube ends can be triggered to close underwater to collect water at a specified depth.

Van Veen grab
A mechanical device designed to collect ocean sediment samples. The device consists of a pair of hinged jaws and a release mechanism that allows the opened jaws to close and entrap a 0.1 m^2 sediment sample once the grab touches bottom.

Wastewater
A mixture of water and waste materials originating from homes, businesses, industries, and sewage treatment plants.

ZID
The zone of initial dilution (ZID) is the region of initial mixing of the surrounding receiving waters with wastewater from the diffuser ports of an outfall. This area includes the underlying seabed. In the ZID, the environment is chronically exposed to pollutants and often is the most impacted.

This page intentionally left blank

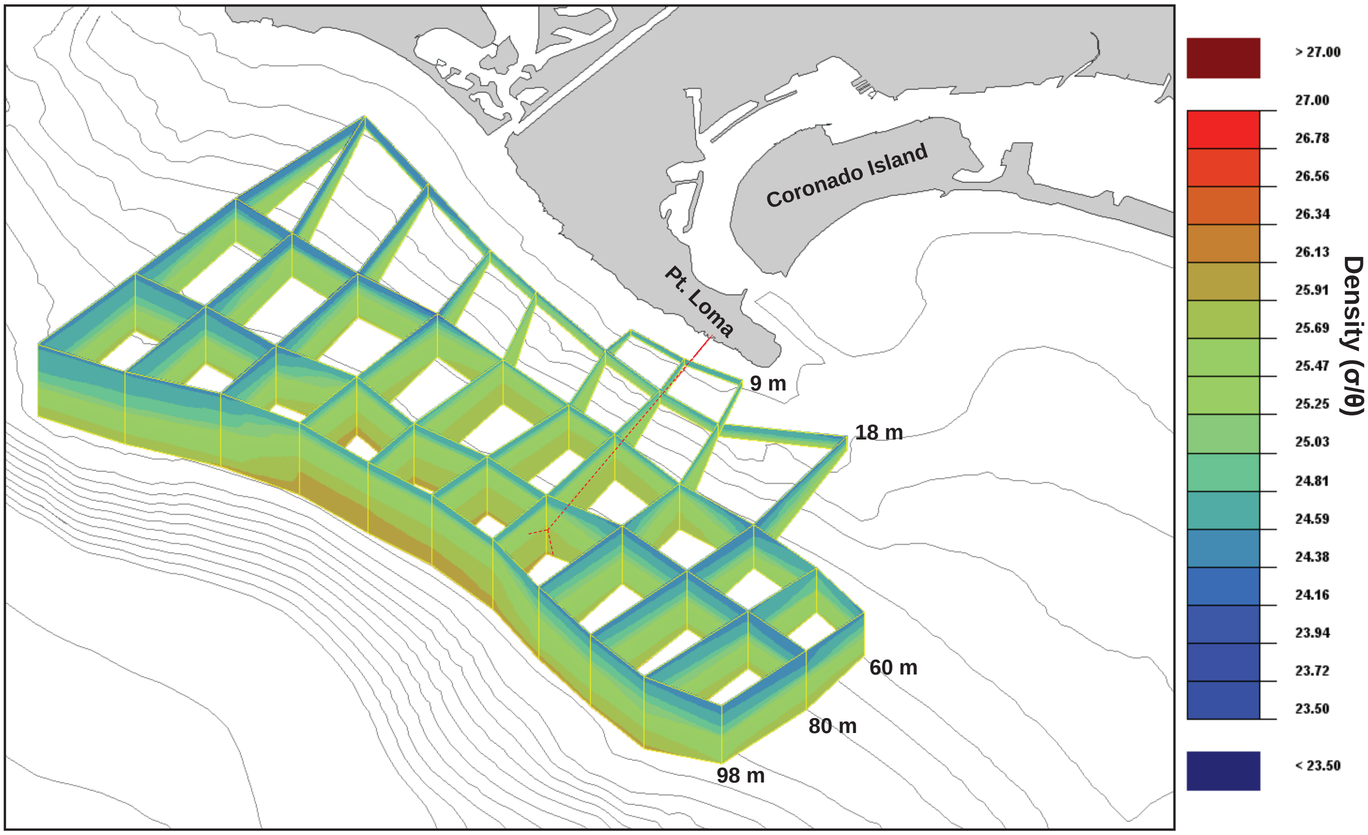
Appendices

Appendix A

Supporting Data

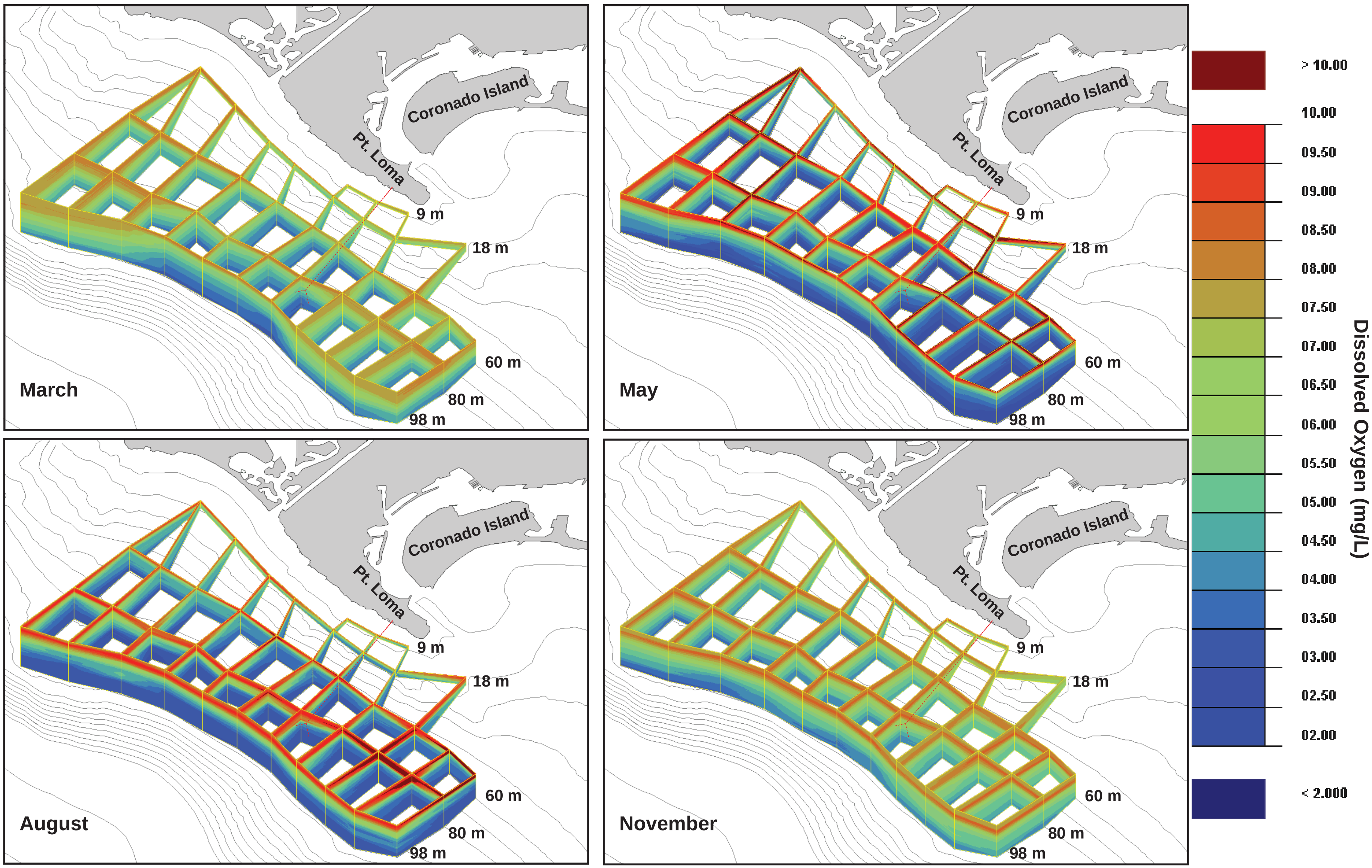
2010 PLOO Stations

Oceanographic Conditions



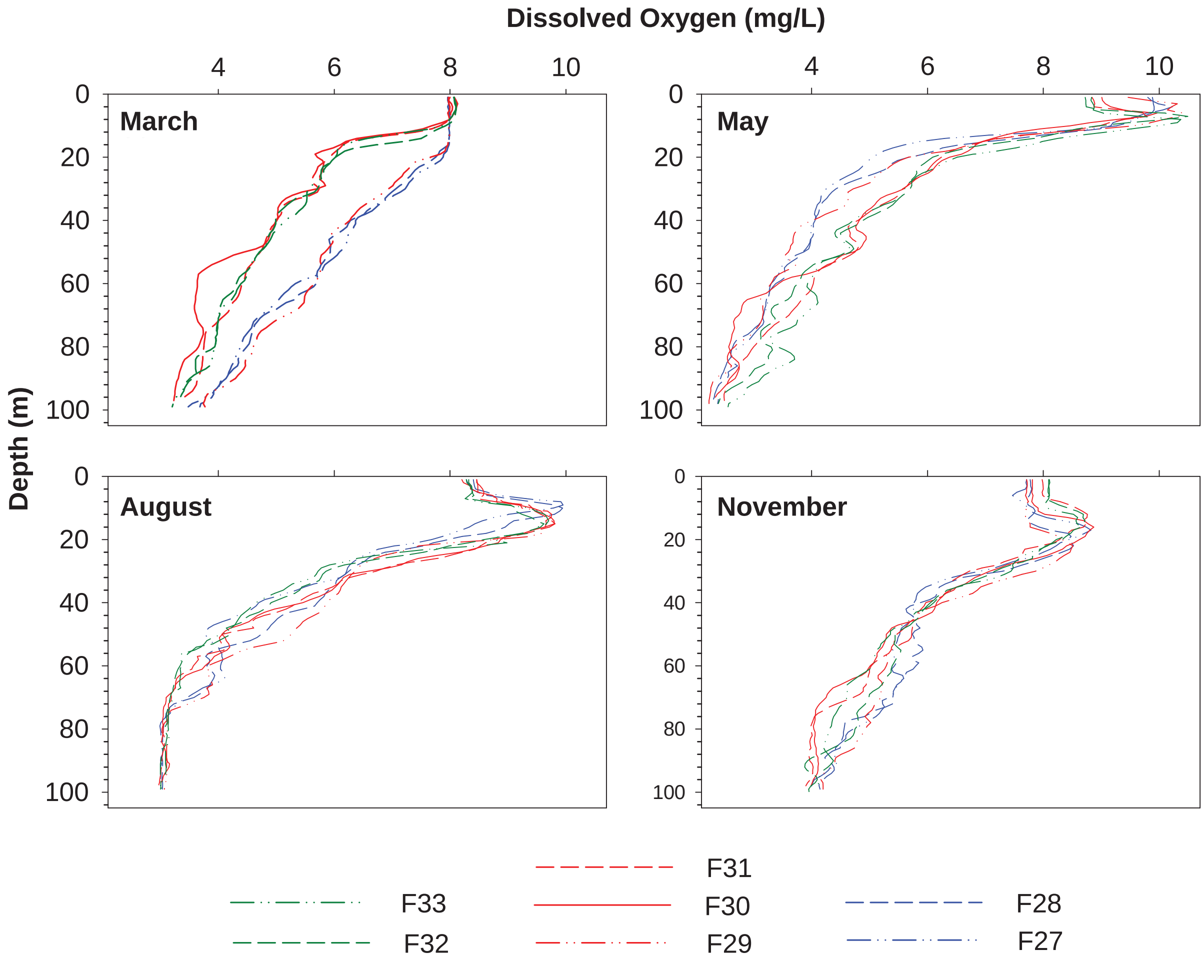
Appendix A.1

Density recorded in 2010 for the PLOO region during March. Data were collected over four days; see Table 2.1 and text for specific sample dates and stations sampled each day.



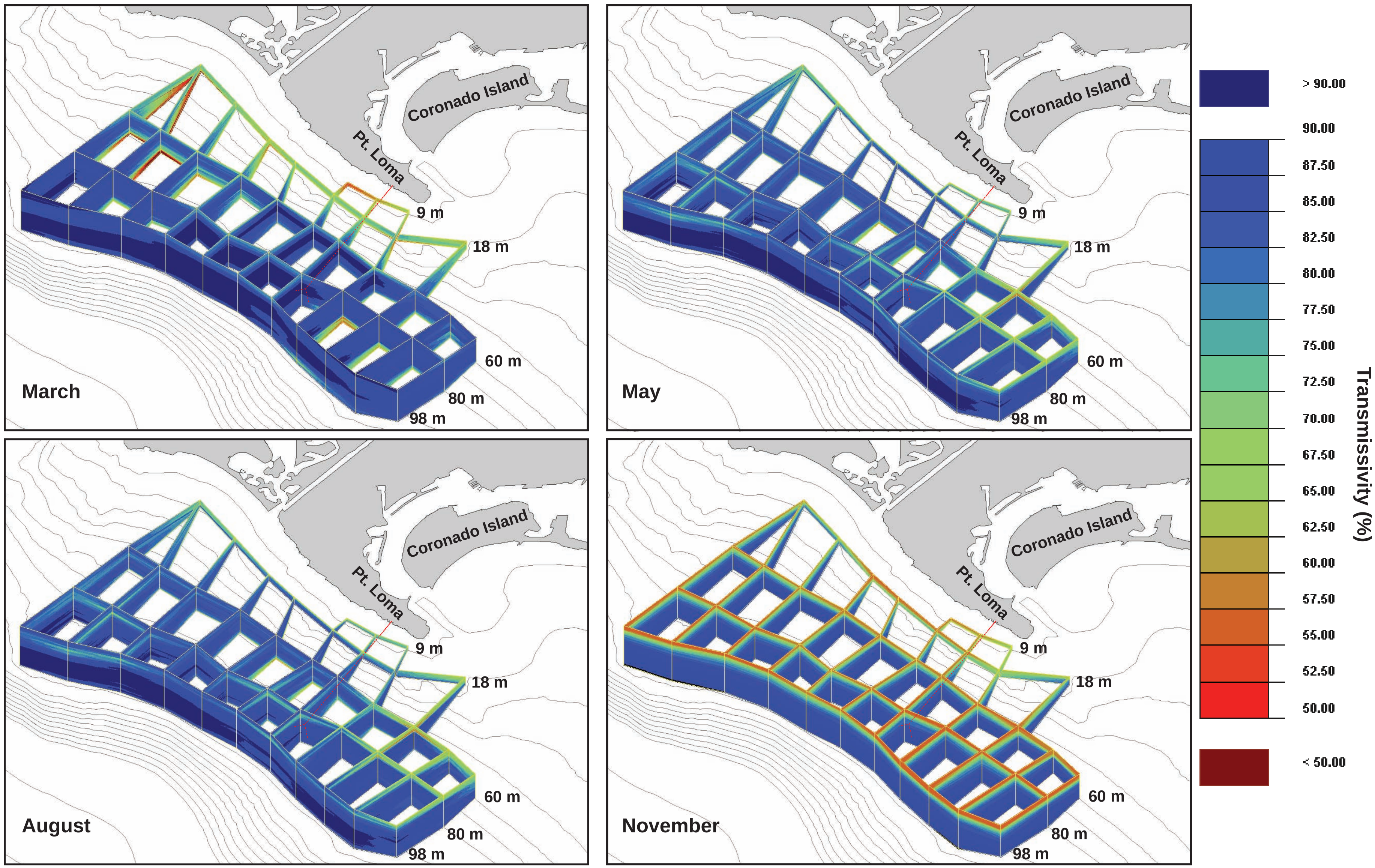
Appendix A.2

Concentrations of dissolved oxygen recorded in 2010 for the PLOO region. Data are collected over four days during each of these quarterly surveys; see Table 2.1 and text for specific sample dates and stations sampled each day.



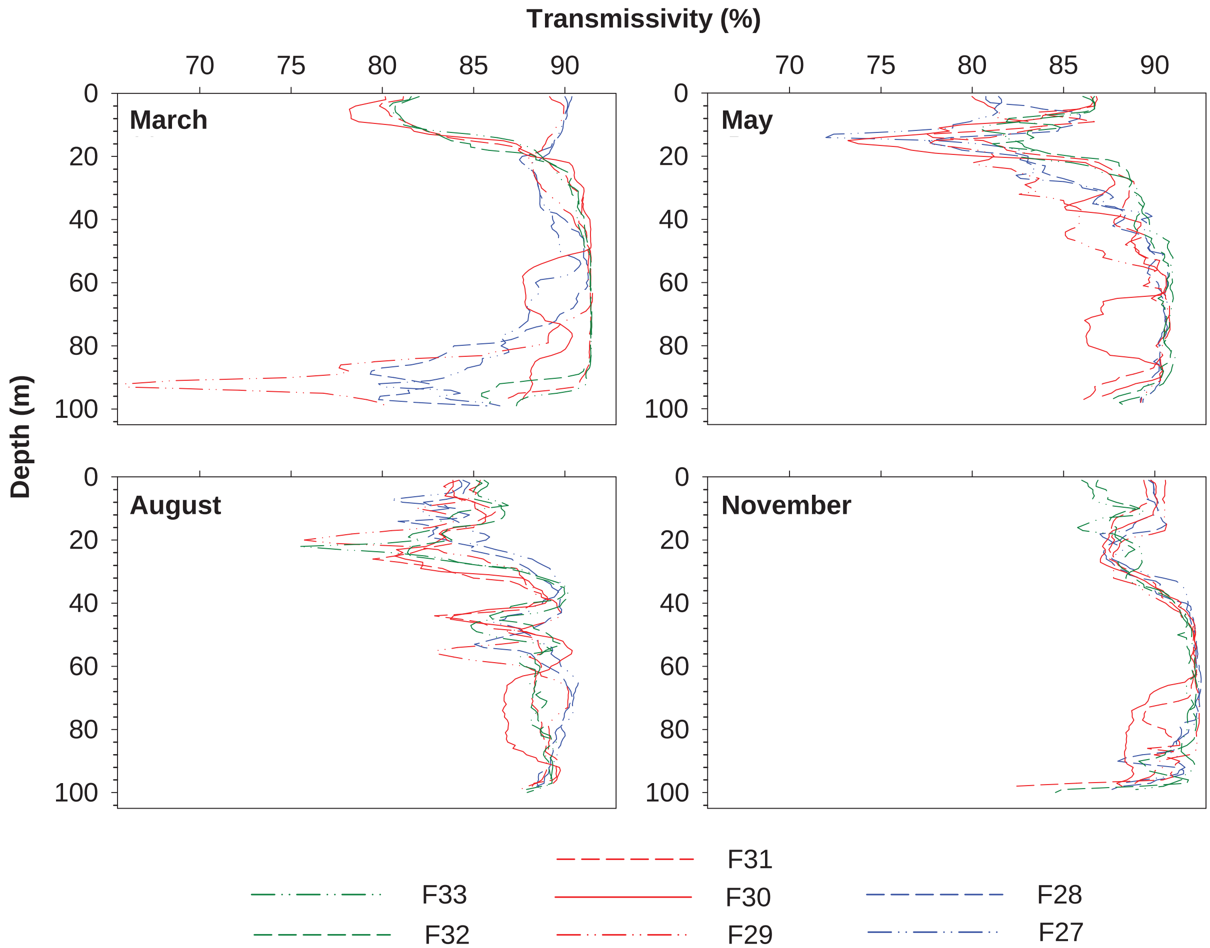
Appendix A.3

Vertical profiles of dissolved oxygen for PLOO stations F27–F33 during each 2010 quarterly survey.



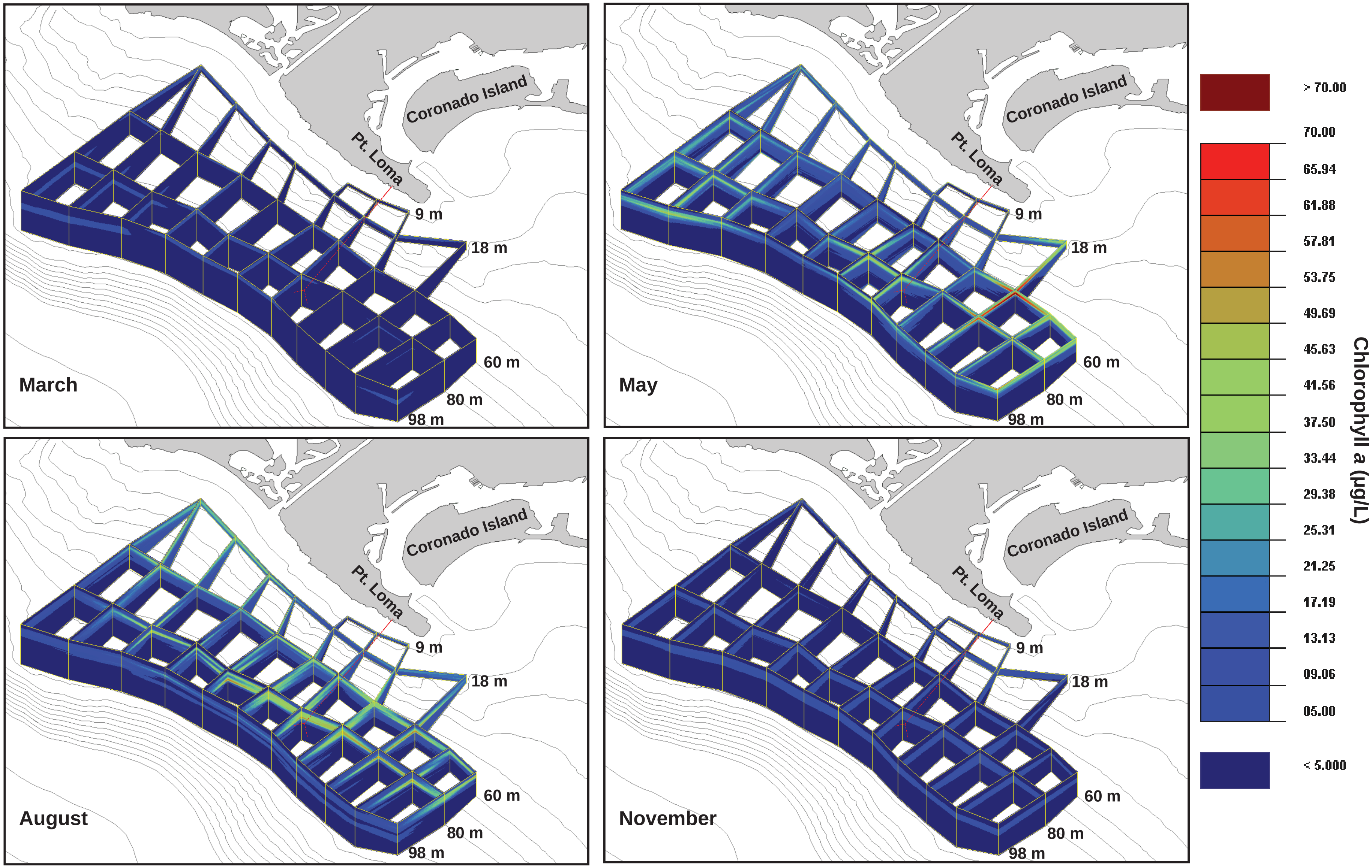
Appendix A.4

Transmissivity recorded in 2010 for the PLOO region. Data are collected over four days during each of these quarterly surveys; see Table 2.1 and text for specific sample dates and stations sampled each day.



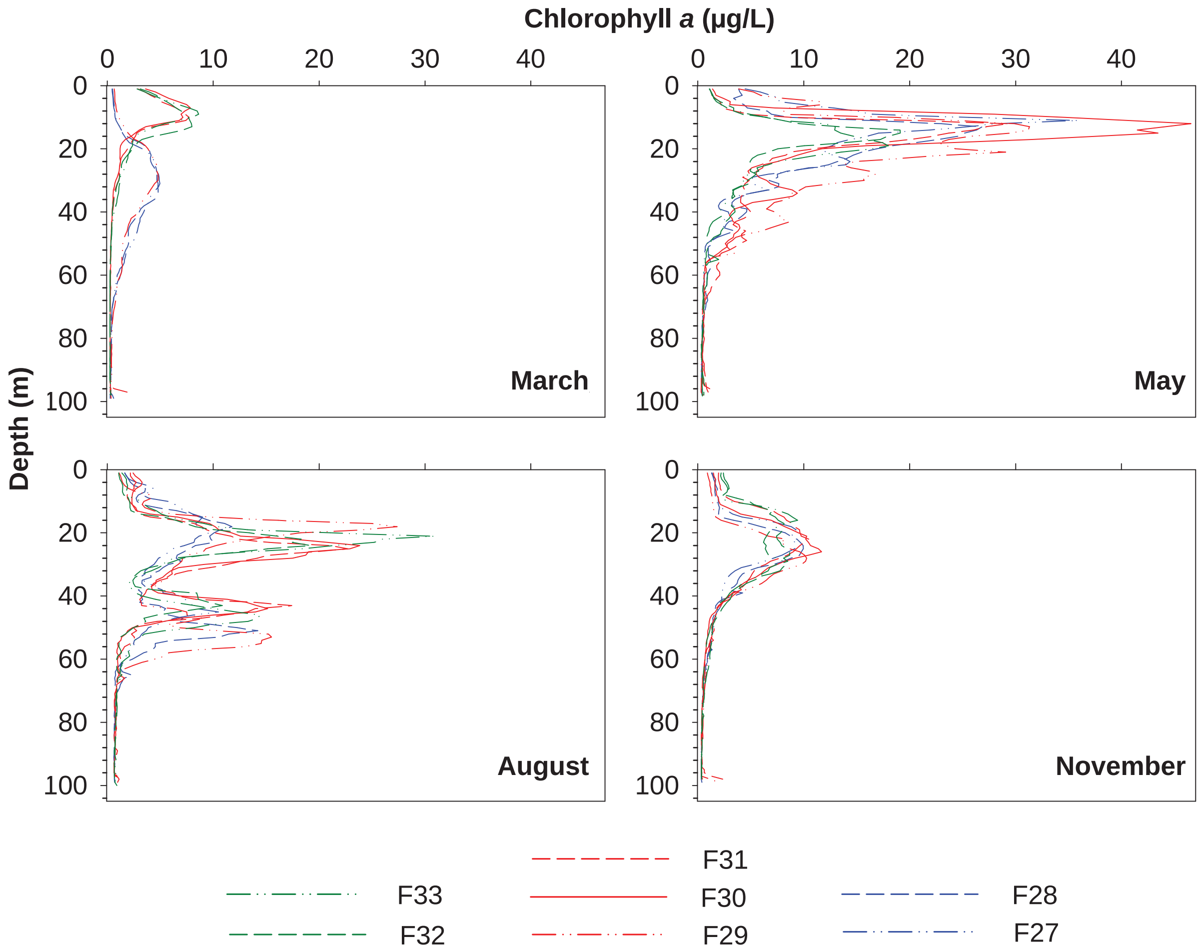
Appendix A.5

Vertical profiles of transmissivity for PLOO stations F27–F33 during each 2010 quarterly survey.

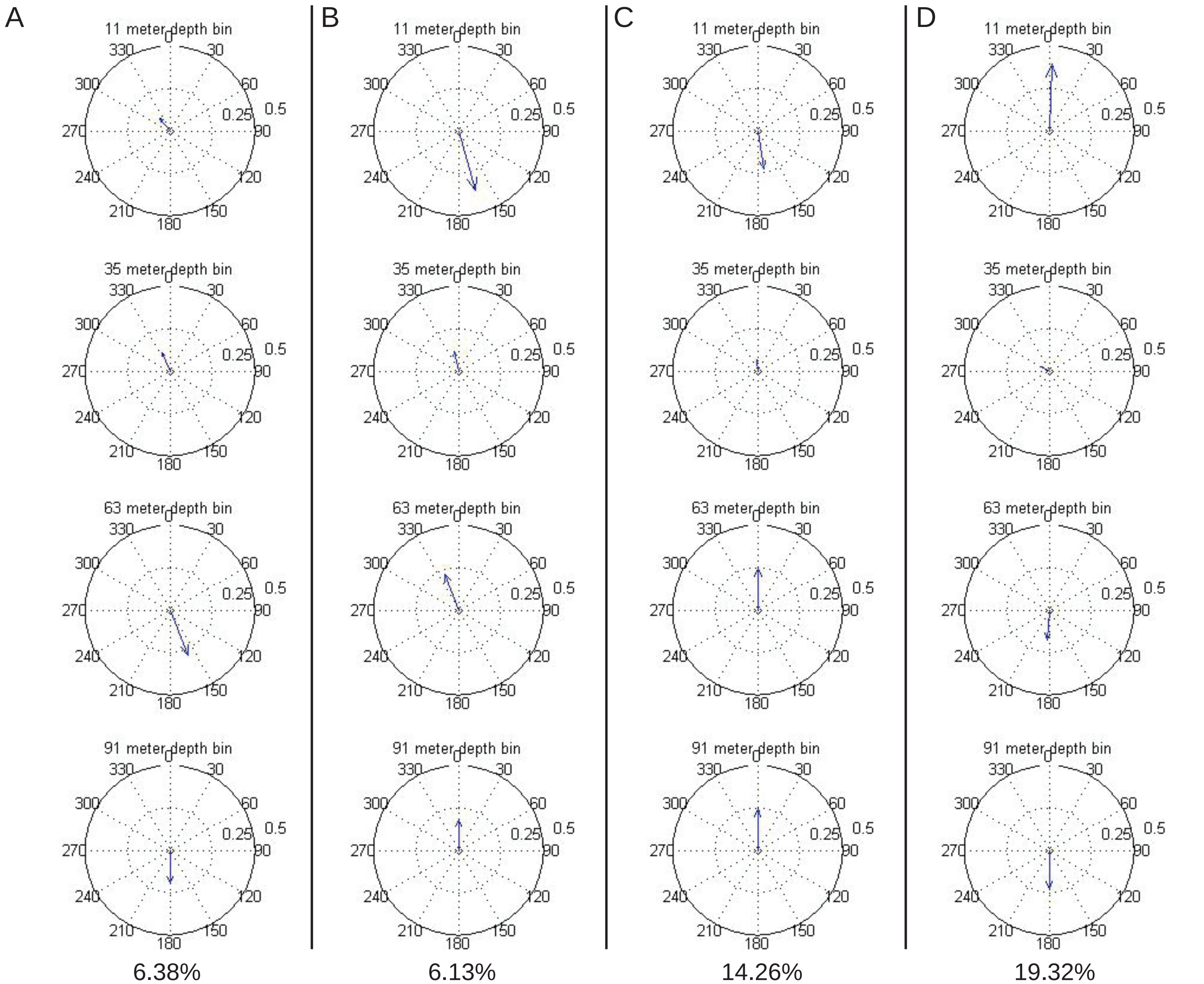


Appendix A.6

Concentrations of chlorophyll *a* recorded in 2010 for the PLOO region. Data are collected over four days during each of these quarterly surveys; see Table 2.1 and text for specific sample dates and stations sampled each day.



Appendix A.7
Vertical profiles of chlorophyll *a* for PLOO stations F27–F33 during each 2010 quarterly survey.



Appendix A.8

Empirical Orthogonal Function 2 (EOF) for (A) winter, (B) spring, (C) summer, and (D) fall in 2010. Percentages indicate fraction of the total variance accounted for by the EOF. Arrow length indicates relative current magnitude.

Appendix B

Supporting Data

2010 PLOO Stations

Water Quality

Appendix B.1

Summary of samples with elevated (bold) total coliform (>10,000 CFU/100 mL), fecal coliform (>400 CFU/100 mL), and/or enterococcus (>104 CFU/100 mL) densities collected at PLOO shore stations during 2010. Bold fecal:total coliform (F:T) values indicate samples which meet the FTR criterion for contamination (i.e., total coliform>1000 CFU/100 mL and F:T>0.10).

Station	Date	Total	Fecal	Entero	F:T
D11	07 Feb 2010	**>16,000**	320	**600**	0.02
D8	11 Oct 2010	no data	400	**110**	—
D12	17 Oct 2010	20	8	**110**	0.40
D5	23 Oct 2010	1000	110	2	0.11
D7	23 Oct 2010	200	240	**680**	1.20
D10	22 Nov 2010	1200	80	**110**	0.07
D4	22 Dec 2010	5400	300	**220**	0.06
D5	22 Dec 2010	2200	260	**520**	**0.12**
D7	22 Dec 2010	1000	120	**360**	0.12
D8	22 Dec 2010	1600	200	**300**	**0.13**
D10	22 Dec 2010	400	20	**140**	0.05
D11	22 Dec 2010	400	60	**320**	0.15
D12	22 Dec 2010	1200	100	**600**	0.08

Appendix B.2

Summary of samples with elevated (bold) total coliform (>10,000 CFU/100 mL), fecal coliform (>400 CFU/100 mL), and/or enterococcus (>104 CFU/100 mL) densities collected at PLOO kelp bed stations during 2010. Bold fecal:total coliform (F:T) values indicate samples which meet the FTR criterion for contamination (i.e., total coliform>1000 CFU/100 mL and F:T>0.10).

Station	Date	Depth (m)	Total	Fecal	Entero	F:T
A1	05 Mar 2010	1	1000	100	14	0.10
A1	22 Mar 2010	18	92	8	**3000**	0.09
C4	22 Mar 2010	3	2	2	**140**	1.00
A6	07 May 2010	1	400	2	**180**	0.01
A7	07 May 2010	1	no data	2	**700**	—
A7	23 Aug 2010	12	2	2	**200**	1.00
A7	06 Nov 2010	1	**14,000**	200	2	0.01

Appendix B.3

Summary of samples with elevated enterococcus (>104 CFU/100 mL) densities collected at PLOO offshore stations during 2010. Values are expressed as CFU/100 mL.

Station	Date	Depth (m)	Enterococcus
F19	12 Mar 2010	60	280
F30	12 Mar 2010	60	300
F30	12 Mar 2010	80	140
F30	12 Mar 2010	98	280
F26	04 May 2010	60	400
F30	06 May 2010	80	380
F30	06 May 2010	98	130
F30	12 Aug 2010	60	110
F31	12 Aug 2010	60	180
F32	12 Aug 2010	60	120
F33	12 Aug 2010	60	920
F30	03 Nov 2010	80	300
F30	03 Nov 2010	98	220
F31	03 Nov 2010	80	240
F31	03 Nov 2010	98	200

Appendix B.4

Summary of compliance with the 2001 California Ocean Plan water contact standards for PLOO shore and kelp bed stations from January 1–July 31, 2010. The values reflect the number of days that each station exceeded the 30-day total coliform, 10,000 total coliform, 60-day fecal coliform, and 30-day fecal geometric mean standards (see Chapter 3; Box 3.1).

	Shore Stations							
Month	**D4**	**D5**	**D7**	**D8**	**D9**	**D10**	**D11**	**D12**
30-Day Total Coliform Standard								
January	0	0	0	6	0	0	0	0
February	0	0	0	0	0	0	21	0
March	0	0	0	0	0	0	9	0
April	0	0	0	0	0	0	17	0
May	0	0	0	0	0	0	1	0
June	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0
Percent Compliance	**100%**	**100%**	**100%**	**97%**	**100%**	**100%**	**77%**	**100%**
10,000 Total Coliform Standard								
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
60-Day Fecal Coliform Standard								
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0
Percent Compliance	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
30-day Fecal Geometric Mean standard								
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0
Percent Compliance	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Appendix B.4 *continued*

	Kelp Bed Stations							
	9-m Stations			18-m Stations				
Month	**C4**	**C5**	**C6**	**A1**	**A7**	**A6**	**C7**	**C8**
30-Day Total Coliform Standard								
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0
Percent Compliance	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
10,000 Total Coliform Standard								
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
60-Day Fecal Coliform Standard								
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0
Percent Compliance	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
30-day Fecal Geometric Mean Standard								
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0
Percent compliance	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Appendix B.5

Summary of compliance with the 2005 California Ocean Plan water contact standards for PLOO shore, kelp bed, and offshore stations from August 1–December 31, 2010. The values reflect the number of times per month that each station exceeded various total coliform, fecal coliform, and enterococcus bacterial standards (see Chapter 3; Box 3.1).

30-day Geometric Mean Standards

	Shore Stations							
Month	**D4**	**D5**	**D7**	**D8**	**D9**	**D10**	**D11**	**D12**
Total Coliform								
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0
Percent Compliance	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
Fecal Coliform								
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0
Percent compliance	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
Enterococcus								
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	4	0
Percent compliance	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**98%**	**100%**

Appendix B.5 *continued*

Single Sample Maximum Standards

	Shore Stations							
Month	**D4**	**D5**	**D7**	**D8**	**D9**	**D10**	**D11**	**D12**
Total Coliform								
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Fecal Coliform								
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Enterococcus								
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	1	1	0	0	0	1
November	0	0	0	0	0	1	0	0
December	2	1	1	1	0	2	2	1
Total	**2**	**1**	**2**	**2**	**0**	**3**	**2**	**2**
Fecal/Total Coliform Ratio (FTR)								
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0
December	0	1	0	1	0	0	0	0
Total	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**0**

Appendix B.5 *continued*

30-day Geometric Mean Standards

	Kelp Bed Stations							
	9-m Stations			18-m Stations				
Month	**C4**	**C5**	**C6**	**A1**	**A7**	**A6**	**C7**	**C8**
Total Coliform								
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0
Percent Compliance	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
Fecal Coliform								
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0
Percent Compliance	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
Enterococcus								
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0
Percent Compliance	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Appendix B.5 *continued*

Single Sample Maximum Standards

	Kelp Bed Stations							
	9-m Stations			18-m Stations				
Month	**C4**	**C5**	**C6**	**A1**	**A7**	**A6**	**C7**	**C8**
Total Coliform								
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
November	0	0	0	0	1	0	0	0
December	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**
Fecal Coliform								
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Enterococcus								
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Fecal/Total Coliform Ratio (FTR)								
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

	Offshore Stations within 3 nautical miles of State waters														
	F02	**F03**	**F11**	**F12**	**F13**	**F14**	**F01**	**F06**	**F18**	**F07**	**F08**	**F09**	**F10**	**F19**	**F20**
Enterococcus															
August	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Appendix C

Supporting Data

2010 PLOO Stations

Sediment Conditions

Appendix C.1

A subset of the Wentworth scale (based on Folk 1980) and modifications used in the analysis of sediments from the PLOO region in 2010. The modified scale was developed to accommodate data output from the Horiba laser analyzer. Particle size is presented in microns, millimeters, and phi size along with descriptions of each size range and how they are classified within size fractions.

Wentworth Scale					
Original	Modified				
Microns	Microns	Millimeters	Phi size	Description	Fraction
≥2000	≥1681	≥1.681	≤-1	Granules–Pebbles	Coarse
1000–1999	931–1680	0.931–1.680	0	Very coarse sand	
500–999	441–930	0.441–0.930	1	Coarse sand	Sand
250–499	246–440	0.246–0.440	2	Medium sand	
125–249	106–245	0.106–0.245	3	Fine sand	
62.5–124	54–105	0.054–0.105	4	Very fine sand	
31–62.4	28–53	0.028–0.053	5	Coarse silt	Silt
15.6–30.9	14.9–27	0.0149–0.027	6	Medium silt	
7.8–15.5	6.0–14.8	0.0060–0.0148	7	Fine silt	
3.9–7.7	3.5–5.9	0.0035–0.0059	8	Very fine silt	
2.0–3.8	1.6–3.4	0.0016–0.0034	9	Clay	Clay
0.98–1.9	0.51–1.5	0.00051–0.0015	10	Clay	
≤0.97	≤0.50	≤0.00050	11	Clay	

Appendix C.2

Constituents and method detection limits (MDLs) for sediment samples analyzed for the PLOO monitoring program during 2010.

Parameter	MDL	Parameter	MDL
Organic Indicators			
Total Sulfides (ppm)	0.14	Total Volatile Solids (% weight)	0.11
Total Nitrogen (% weight)	0.005	Biochemical Oxygen Demand (ppm)	2
Total Organic Carbon (% weight)	0.01		
Metals (ppm)			
Aluminum (Al)	2	Lead (Pb)	0.8
Antimony (Sb)	0.3	Manganese (Mn)	0.08
Arsenic (As)	0.33	Mercury (Hg)	0.003
Barium (Ba)	0.02	Nickel (Ni)	0.1
Beryllium (Be)	0.01	Selenium (Se)	0.24
Cadmium (Cd)	0.06	Silver (Ag)	0.04
Chromium (Cr)	0.1	Thallium (Tl)	0.5
Copper (Cu)	0.2	Tin (Sn)	0.3
Iron (Fe)	9	Zinc (Zn)	0.25
Pesticides (ppt)			
Hexachlorocyclohexane (HCH)			
HCH, Alpha isomer	400	HCH, Delta isomer	400
HCH, Beta isomer	400	HCH, Gamma isomer	400
Total Chlordane			
Alpha (cis) Chlordane	700	Heptachlor epoxide	700
Cis Nonachlor	700	Methoxychlor	700
Gamma (trans) Chlordane	700	Oxychlordane	700
Heptachlor	700	Trans Nonachlor	700
Total Dichlorodiphenyltrichloroethane (DDT)			
o,p-DDD	400	p,p-DDE	400*
o,p-DDE	700	p,p-DDMU	**
o,p-DDT	700	p,p-DDT	700
p,p-DDD	700		
Miscellaneous Pesticides			
Aldrin	700	Endrin	700
Alpha Endosulfan	700	Endrin aldehyde	700
Beta Endosulfan	700	Hexachlorobenzene (HCB)	400
Dieldrin	700	Mirex	700
Endosulfan Sulfate	700		

* MDL for p,p-DDE = 700 for analysis of samples from E2 and E8 in July 2010
** No MDL available for this parameter

Appendix C.2 *continued*

Parameter	MDL	Parameter	MDL
Polychlorinated Biphenyl Congeners (PCBs) (ppt)			
PCB 18	700	PCB 126	1500
PCB 28	700	PCB 128	700
PCB 37	700	PCB 138	700
PCB 44	700	PCB 149	700
PCB 49	700	PCB 151	700
PCB 52	700	PCB 153/168	700
PCB 66	700	PCB 156	700
PCB 70	700	PCB 157	700
PCB 74	700	PCB 158	700
PCB 77	700	PCB 167	700
PCB 81	700	PCB 169	700
PCB 87	700	PCB 170	700
PCB 99	700	PCB 177	700
PCB 101	700	PCB 180	400
PCB 105	700	PCB 183	700
PCB 110	700	PCB 187	700
PCB 114	700	PCB 189	400
PCB 118	700	PCB 194	700
PCB 119	700	PCB 201	700
PCB 123	700	PCB 206	700
Polycyclic Aromatic Hydrocarbons (PAHs) (ppb)			
1-methylnaphthalene	20	Benzo[K]fluoranthene	20
1-methylphenanthrene	20	Benzo[e]pyrene	20
2,3,5-trimethylnaphthalene	20	Biphenyl	30
2,6-dimethylnaphthalene	20	Chrysene	40
2-methylnaphthalene	20	Dibenzo(A,H)anthracene	20
3,4-benzo(B)fluoranthene	20	Fluoranthene	20
Acenaphthene	20	Fluorene	20
Acenaphthylene	30	Indeno(1,2,3-CD)pyrene	20
Anthracene	20	Naphthalene	30
Benzo[A]anthracene	20	Perylene	30
Benzo[A]pyrene	20	Phenanthrene	30
Benzo[G,H,I]perylene	20	Pyrene	20

Appendix C.3

Summary of tDDT, tPCB, and tPAH constituents in sediment samples collected during the January and July surveys of the PLOO monitoring program during 2010.

Station	Class	Constituent	January	July	Units
B8	DDT	p,p-DDE	330	260	ppt
B9	DDT	o,p-DDT	nd	4900	ppt
B9	DDT	p,p-DDE	580	490	ppt
B9	DDT	p,p-DDT	nd	6900	ppt
B10	DDT	p,p-DDE	310	230	ppt
B11	DDT	p,p-DDE	220	nd	ppt
B12	DDT	p,p-DDE	250	<MDL	ppt
E1	DDT	p,p-DDE	760	470	ppt
E1	PAH	3,4-benzo(B)fluoranthene	54.5	21.2	ppb
E1	PAH	Benzo[A]anthracene	32.6	nd	ppb
E1	PAH	Benzo[A]pyrene	40.6	nd	ppb
E1	PAH	Benzo[e]pyrene	27.4	nd	ppb
E1	PAH	Benzo[G,H,I]perylene	27.8	nd	ppb
E1	PAH	Fluoranthene	39.3	nd	ppb
E1	PAH	Indeno(1,2,3-CD)pyrene	20.5	nd	ppb
E1	PAH	Pyrene	51.7	nd	ppb
E1	PCB	PCB 66	350	nd	ppt
E1	PCB	PCB 70	250	nd	ppt
E1	PCB	PCB 99	230	nd	ppt
E1	PCB	PCB 101	600	nd	ppt
E1	PCB	PCB 105	110	81	ppt
E1	PCB	PCB 110	500	300	ppt
E1	PCB	PCB 118	270	170	ppt
E1	PCB	PCB 128	120	nd	ppt
E1	PCB	PCB 138	450	270	ppt
E1	PCB	PCB 149	340	380	ppt
E1	PCB	PCB 151	110	nd	ppt
E1	PCB	PCB 153/168	230	140	ppt
E1	PCB	PCB 156	42	nd	ppt
E1	PCB	PCB 170	98	nd	ppt
E1	PCB	PCB 177	110	nd	ppt
E1	PCB	PCB 180	1200	450	ppt
E1	PCB	PCB 183	140	nd	ppt
E1	PCB	PCB 187	150	nd	ppt

nd = not detected; <MDL=Average of lab duplicates below MDL (see City of San Diego 2011)

Appendix C.3 *continued*

Station	Class	Constituent	January	July	Units
E1	PCB	PCB 206	150	nd	ppt
E2	DDT	p,p-DDE	870	270	ppt
E2	DDT	p,p-DDT	1000	nd	ppt
E2	PAH	3,4-benzo(B)fluoranthene	35.5	nd	ppb
E2	PAH	Benzo[A]anthracene	23.3	nd	ppb
E2	PAH	Benzo[A]pyrene	24.6	nd	ppb
E2	PCB	PCB 105	140	nd	ppt
E2	PCB	PCB 110	340	nd	ppt
E2	PCB	PCB 118	250	nd	ppt
E2	PCB	PCB 149	440	nd	ppt
E2	PCB	PCB 153/168	210	nd	ppt
E2	PCB	PCB 187	99	nd	ppt
E3	DDT	p,p-DDE	210	240	ppt
E3	PAH	3,4-benzo(B)fluoranthene	33.4	nd	ppb
E3	PAH	Benzo[A]anthracene	24.5	nd	ppb
E3	PAH	Benzo[A]pyrene	23.2	20.4	ppb
E3	PCB	PCB 52	nd	<MDL	ppt
E3	PCB	PCB 66	nd	160	ppt
E3	PCB	PCB 70	nd	300	ppt
E3	PCB	PCB 87	nd	<MDL	ppt
E3	PCB	PCB 99	nd	<MDL	ppt
E3	PCB	PCB 101	nd	<MDL	ppt
E3	PCB	PCB 105	nd	<MDL	ppt
E3	PCB	PCB 110	140	290	ppt
E3	PCB	PCB 118	120	<MDL	ppt
E3	PCB	PCB 128	nd	<MDL	ppt
E3	PCB	PCB 138	150	220	ppt
E3	PCB	PCB 149	170	510	ppt
E3	PCB	PCB 153/168	99	150	ppt
E3	PCB	PCB 156	nd	<MDL	ppt
E3	PCB	PCB 158	nd	<MDL	ppt
E3	PCB	PCB 177	nd	<MDL	ppt
E3	PCB	PCB 180	nd	270	ppt
E3	PCB	PCB 187	59	nd	ppt
E5	DDT	p,p-DDE	350	230	ppt
E5	PCB	PCB 118	52	nd	ppt
E5	PCB	PCB 153/168	31	nd	ppt

nd = not detected; <MDL=Average of lab duplicates below MDL (see City of San Diego 2011)

Appendix C.3 *continued*

Station	Class	Constituent	January	July	Units
E7	DDT	p,p-DDE	530	220	ppt
E7	PCB	PCB 153/168	53	nd	ppt
E8	DDT	p,p-DDE	nd	190	ppt
E8	PCB	PCB 138	nd	150	ppt
E8	PCB	PCB 153/168	<MDL	nd	ppt
E9	DDT	p,p-DDE	190	230	ppt
E9	PCB	PCB 110	97	nd	ppt
E9	PCB	PCB 118	98	nd	ppt
E9	PCB	PCB 138	110	nd	ppt
E9	PCB	PCB 149	86	nd	ppt
E9	PCB	PCB 153/168	52	nd	ppt
E9	PCB	PCB 180	360	nd	ppt
E11	DDT	p,p-DDE	290	210	ppt
E14	DDT	p,p-DDE	190	160	ppt
E15	DDT	p,p-DDE	310	210	ppt
E17	DDT	p,p-DDE	210	250	ppt
E17	PCB	PCB 105	nd	160	ppt
E17	PCB	PCB 110	nd	380	ppt
E17	PCB	PCB 118	nd	230	ppt
E17	PCB	PCB 138	nd	330	ppt
E17	PCB	PCB 149	83	330	ppt
E17	PCB	PCB 153/168	nd	150	ppt
E17	PCB	PCB 180	nd	450	ppt
E19	DDT	p,p-DDE	600	230	ppt
E20	DDT	p,p-DDE	240	280	ppt
E21	DDT	p,p-DDE	370	300	ppt
E21	PCB	PCB 138	160	nd	ppt
E21	PCB	PCB 149	180	nd	ppt
E21	PCB	PCB 151	190	nd	ppt
E21	PCB	PCB 153/168	170	nd	ppt
E21	PCB	PCB 177	320	nd	ppt
E21	PCB	PCB 180	2200	nd	ppt

nd = not detected; <MDL=Average of lab duplicates below MDL (see City of San Diego 2011)

Appendix C.3 *continued*

Station	Class	Constituent	January	July	Units
E21	PCB	PCB 183	370	nd	ppt
E21	PCB	PCB 187	870	nd	ppt
E21	PCB	PCB 194	630	nd	ppt
E21	PCB	PCB 201	1100	nd	ppt
E21	PCB	PCB 206	880	nd	ppt
E23	DDT	p,p-DDE	420	250	ppt
E23	PCB	PCB 118	55	nd	ppt
E23	PCB	PCB 138	100	nd	ppt
E25	DDT	p,p-DDE	370	380	ppt
E26	DDT	p,p-DDE	450	280	ppt

nd = not detected

Appendix C.4

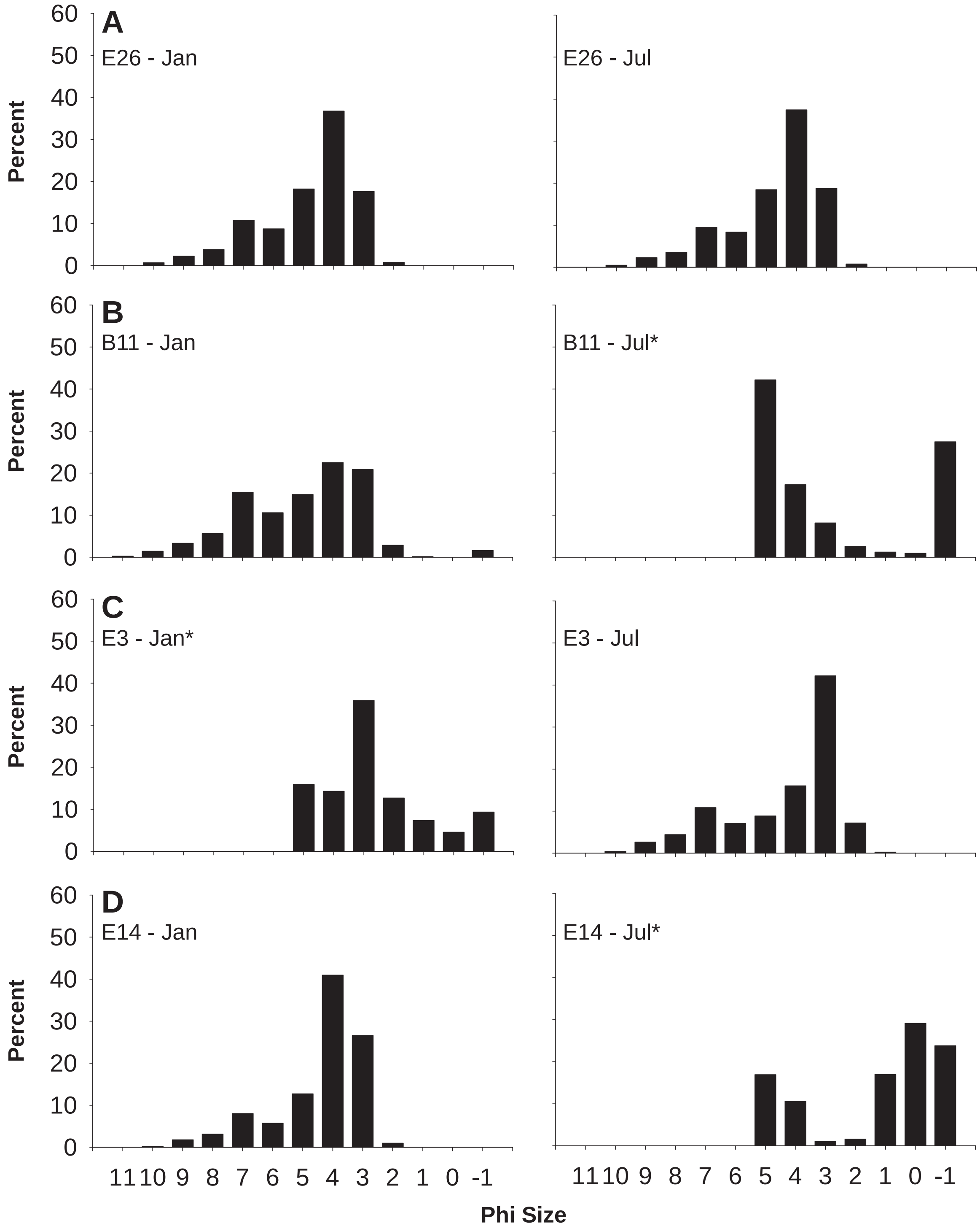
PLOO sediment statistics for the January 2010 survey. Silt and clay fractions are indiscernible for samples analyzed by sieve. Visual observations of sediments were made in the field at the time of collection as well as on the sieved “grunge” (i.e., particles retained on 1-mm mesh screen and preserved with infauna for benthic community analysis). * = nearfield stations; SD = standard deviation; Pre-discharge period = 1991–1993.

	Mean (mm)	Mean (phi)	SD (phi)	Median (phi)	Skewness (phi)	Kurtosis (phi)	Coarse (%)	Sand (%)	Silt (%)	Clay (%)	Fines (%)	Visual Observations
88-m Depth Contour												
B11	0.045	4.46	1.89	4.12	0.3	0.8	1.7	46.5	46.7	5.1	51.8	Silt, sand, coarse sand, pea gravel, shell hash
B8	0.042	4.58	1.54	4.20	0.4	1.0	0.0	42.9	53.4	3.8	57.1	Silt
E19	0.049	4.35	1.51	3.93	0.4	1.1	0.0	52.6	44.0	3.4	47.4	Silt with fine sand
E7	0.052	4.27	1.50	3.85	0.4	1.1	0.0	54.9	42.4	2.7	45.1	Silt, shell hash
E1	0.056	4.17	1.70	3.71	0.4	0.9	0.0	56.5	40.5	3.1	43.5	Silt, coarse sand, pea gravel, rock, shell hash
98-m Depth Contour												
B12	0.063	3.99	1.82	3.29	0.5	0.8	0.0	63.0	34.2	2.8	37.0	Sand, silt, coarse sand, pea gravel, shell hash
B9	0.052	4.28	1.65	3.73	0.5	1.0	0.0	57.4	39.0	3.6	42.6	Silt, pea gravel, mud balls
E26	0.050	4.31	1.55	3.83	0.4	1.0	0.0	55.2	41.7	3.0	44.8	Silt with some shell hash and organic material
E25	0.056	4.17	1.50	3.70	0.5	1.1	0.0	59.5	37.9	2.5	40.4	Silt with some pea gravel and shell hash
E23	0.054	4.21	1.50	3.76	0.4	1.1	0.0	58.1	38.9	3.0	41.9	Silt with shell hash and organic material
E20	0.064	3.97	1.38	3.58	0.5	1.3	0.0	64.3	33.5	2.2	35.7	Silt with fine sand, shell hash, organic material
E17*	0.066	3.93	1.40	3.57	0.4	1.2	0.0	67.4	30.4	2.2	32.6	Silt and fine sand
E14*	0.068	3.88	1.37	3.42	0.5	1.3	0.0	68.5	29.5	2.0	31.5	Gravel, silt, coarse black sand, shell hash
E11*	0.068	3.87	1.35	3.48	0.5	1.3	0.0	67.3	30.7	2.0	32.7	Silt, shell hash
E8	0.068	3.87	1.38	3.46	0.5	1.3	0.0	67.1	30.8	2.0	32.8	Silt
E5	0.064	3.97	1.45	3.58	0.4	1.2	0.0	65.8	31.8	2.3	34.1	Silt
E2	0.054	4.21	1.68	3.74	0.4	0.9	0.0	57.6	39.0	3.3	42.4	Silt, shell hash, coarse sand, pea gravel, rock
116-m Depth Contour												
B10	0.066	3.93	1.50	3.41	0.5	1.2	0.0	70.5	27.5	2.0	29.5	Silt with sand, some shell hash
E21	0.063	3.98	1.44	3.47	0.5	1.3	0.0	66.4	31.3	2.3	33.6	Silt with fine sand
E15*	0.068	3.88	1.40	3.38	0.6	1.4	0.0	69.1	28.6	2.3	30.9	Silt with some shell hash
E9	0.049	4.35	1.76	3.75	0.5	0.9	0.0	56.1	39.3	4.5	43.9	Sand, silt, lots of coarse black sand, shell hash
E3	0.210	2.25	1.73	2.44	-0.2	1.1	13.9	70.2	—	—	15.9	Silt, fine sand, shell hash, coarse sand, gravel
January Max	0.210	4.58	1.89	4.20	0.6	1.4	13.9	70.5	53.4	5.1	57.1	
Pre-discharge Max	0.125	5.80	3.00	5.60	1.9	8.1	26.4	79.0	62.0	13.9	74.2	

Appendix C.4 *continued*

PLOO sediment statistics for the July 2010 survey. Silt and clay fractions are indiscernible for samples analyzed by sieve. Visual observations of sediments were made in the field at the time of collection as well as on the sieved "grunge" (i.e., particles retained on 1-mm mesh screen and preserved with infauna for benthic community analysis). * = nearfield stations; SD = standard deviation. Pre-discharge period = 1991–1993.

	Mean (mm)	Mean (phi)	SD (phi)	Median (phi)	Skewness (phi)	Kurtosis (phi)	Coarse (%)	Sand (%)	Silt (%)	Clay (%)	Fines (%)	Visual Observations
88-m Depth Contour												
B11	0.184	2.44	2.41	3.59	-0.6	0.4	28.5	29.3	—	—	42.2	Silt, cobble, fine sand, gravel, shell hash
B8	0.040	4.65	1.53	4.34	0.3	0.9	0.0	41.7	54.6	3.7	58.3	Silt
E19	0.049	4.34	1.48	3.93	0.4	1.1	0.0	52.6	44.7	2.7	47.4	Silt with some shell hash and organic material
E7	0.055	4.18	1.47	3.79	0.4	1.1	0.0	58.7	39.0	2.3	41.3	Silt with fine sand
E1	0.059	4.09	1.64	3.65	0.4	1.0	1.1	58.7	37.5	2.7	40.2	Fine sand, shell hash, coarse red sand, gravel
98-m Depth Contour												
B12	0.068	3.87	1.76	3.13	0.6	1.0	0.0	67.5	29.9	2.6	32.5	Sand with silt, pea gravel, shell hash
B9	0.054	4.22	1.65	3.75	0.4	1.0	1.3	57.3	38.5	2.9	41.4	Silt, mud pea gravel
E26	0.053	4.25	1.51	3.83	0.4	1.1	0.0	57.1	40.0	2.9	42.9	Silt with some shell hash and organic material
E25	0.054	4.21	1.52	3.77	0.4	1.1	0.0	59.1	38.2	2.7	40.9	Silt with some shell hash and organic material
E23	0.056	4.17	1.48	3.72	0.5	1.1	0.0	59.4	38.1	2.5	40.6	Silt with some shell hash and organic material
E20	0.061	4.05	1.43	3.59	0.5	1.2	0.0	63.4	34.4	2.2	36.6	Silt with some shell hash and organic material
E17*	0.064	3.96	1.42	3.50	0.5	1.3	0.0	66.0	31.8	2.2	34.0	Silt, fine sand, shell hash, organic material
E14*	0.517	0.95	2.09	-0.09	0.6	0.5	52.9	30.2	—	—	16.8	Lots of gravel, coarse black sand, rocks, shell hash
E11*	0.070	3.84	1.34	3.50	0.4	1.3	0.0	69.6	28.5	1.8	30.3	Silt with fine sand, shell hash, organic material
E8	0.065	3.95	1.42	3.56	0.4	1.2	0.0	66.7	31.1	2.1	33.2	Silt with fine sand
E5	0.065	3.95	1.42	3.56	0.4	1.2	0.0	66.4	31.4	2.2	33.6	Silt with fine sand, some black sand, shell hash
E2	0.057	4.14	1.65	3.63	0.5	1.0	0.0	59.4	37.6	3.0	40.6	Fine sand, shell hash, coarse red sand, gravel
116-m Depth Contour												
B10	0.063	4.00	1.58	3.45	0.5	1.1	0.0	68.4	28.9	2.6	31.5	Silt, shell hash, rocks
E21	0.063	3.98	1.45	3.44	0.6	1.2	0.0	66.4	31.3	2.3	33.6	Silt, clay, shell hash, and organic material
E15*	0.066	3.93	1.43	3.43	0.5	1.3	0.0	67.5	30.2	2.2	32.5	Silt, fine sand, shell hash, coarse black sand, gravel
E9	0.054	4.21	1.65	3.72	0.4	1.1	0.9	59.1	36.6	3.3	39.9	Silt, coarse sand, shell hash, coarse black sand
E3	0.071	3.82	1.87	3.02	0.6	0.8	0.0	65.7	31.3	3.1	34.3	Fine sand, shell hash, coarse red sand, gravel
July Max	0.517	4.65	2.41	4.34	0.6	1.3	52.9	69.6	54.6	3.7	58.3	
Pre-discharge Max	0.125	5.80	3.00	5.60	1.9	8.1	26.4	79.0	62.0	13.9	74.2	



Appendix C.5

Select histograms illustrating particle size distributions of PLOO sediments in 2010. (A) Station E26 represents the general shape of the particle size distribution at most stations. Note the consistency in shape between January and July surveys; (B–D) Stations with inconsistently shaped particle size distributions between surveys. An asterisk indicates samples analyzed by sieve; therefore the bar at phi 5 represents all material finer than phi 4 (see text).

Appendix C.6

Summary of organic loading indicators at PLOO benthic stations for the January and July 2010 surveys. * = nearfield stations; DR = detection rate.

	January					July				
	BOD (ppm)	Sulfides (ppm)	TN (% wt)	TOC (% wt)	TVS (% wt)	BOD (ppm)	Sulfides (ppm)	TN (% wt)	TOC (% wt)	TVS (% wt)
88-m Depth Contour										
B11	390	1.75	0.093	3.550	3.7	402	3.33	0.098	1.370	4.3
B8	399	0.50	0.090	0.978	3.1	355	1.34	0.085	0.752	3.0
E19	359	2.49	0.062	0.690	2.6	438	4.56	0.074	0.642	2.6
E7	399	0.58	0.064	0.731	2.5	409	3.11	0.069	0.580	2.3
E1	304	2.29	0.052	0.624	2.4	311	7.65	0.054	0.460	2.1
98-m Depth Contour										
B12	474	2.04	0.058	4.810	3.1	370	0.71	0.072	2.140	3.0
B9	313	0.42	0.062	1.030	2.7	270	1.79	0.070	0.681	3.1
E26	275	0.90	0.062	0.711	2.6	514	16.80	0.070	0.604	2.5
E25	261	0.93	0.056	0.807	2.1	328	2.61	0.061	0.522	2.5
E23	288	0.50	0.057	0.645	2.3	403	3.41	0.061	0.522	2.3
E20	247	4.70	0.046	0.522	2.0	382	7.05	0.055	0.470	2.0
E17*	331	18.40	0.047	0.524	2.0	298	12.00	0.054	0.468	1.9
E14*	361	2.86	0.042	0.648	1.7	368	16.50	0.065	0.862	1.3
E11*	436	6.13	0.044	0.666	2.0	980	15.40	0.062	0.521	2.0
E8	256	0.45	0.040	0.642	1.8	171	3.31	0.050	0.434	1.9
E5	225	1.16	0.051	0.813	2.2	339	8.86	0.054	0.455	2.1
E2	354	2.03	0.053	0.774	2.6	209	4.00	0.056	0.478	2.4
116-m Depth Contour										
B10	407	1.09	0.053	1.470	2.3	349	8.64	0.052	1.320	2.8
E21	231	5.89	0.054	0.628	2.1	525	5.12	0.057	0.489	2.3
E15*	268	1.20	0.044	0.678	2.2	298	2.83	0.057	0.495	2.3
E9	307	1.63	0.049	1.760	2.7	240	4.70	0.050	0.655	2.3
E3	156	1.30	0.036	0.607	1.7	245	6.70	0.042	0.360	1.9
DR (%)	100	100	100	100	100	100	100	100	100	100

Appendix C.7

Concentrations of trace metals (ppm) for the January 2010 PLOO survey. * = nearfield stations; ERL = Effects Range Low threshold value; ERM = Effects Range Median threshold value. See Appendix C.2 for MDLs and names for each metal represented by periodic table symbol.

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
88-m Depth Contour																		
B11	9750	1.20	4.59	40.00	nd	0.17	23.5	9.08	19,000	6.33	152.0	0.033	9.16	nd	nd	nd	1.8	44.9
B8	15,200	<MDL	4.22	58.30	nd	0.28	24.5	11.90	16,500	8.00	135.0	0.038	10.20	nd	nd	nd	1.4	39.4
E19	10,200	0.31	3.22	50.80	nd	0.15	19.4	10.40	13,400	7.18	112.0	0.035	9.42	nd	nd	nd	1.5	37.6
E7	11,900	nd	3.27	51.30	nd	0.17	20.1	10.50	13,800	6.00	120.0	0.036	9.13	nd	nd	nd	1.2	34.5
E1	9710	nd	2.23	48.20	nd	0.11	16.9	12.00	12,400	7.88	101.0	0.054	7.12	nd	nd	nd	1.0	32.9
98-m Depth Contour																		
B12	7740	0.47	5.42	23.30	nd	0.17	24.4	4.25	22,100	4.22	59.8	0.015	6.08	nd	nd	nd	1.7	34.8
B9	9260	nd	3.11	67.20	nd	0.15	21.9	7.39	15,800	5.61	98.9	0.026	7.80	nd	nd	nd	0.9	34.0
E26	6120	nd	2.39	40.90	nd	nd	10.7	4.21	7290	1.85	72.4	0.028	3.93	nd	nd	nd	0.8	21.4
E25	9280	nd	2.02	40.40	nd	0.13	17.4	8.19	11,700	4.93	97.0	0.026	8.28	nd	nd	nd	1.7	33.3
E23	8540	nd	2.51	40.10	nd	0.12	16.6	9.39	11,300	4.77	91.2	0.025	7.94	nd	nd	nd	1.1	32.0
E20	7840	nd	2.32	33.40	nd	0.12	14.9	8.20	10,100	3.83	80.9	0.021	7.21	nd	nd	nd	0.9	27.9
E17*	3450	nd	2.13	15.30	nd	0.06	7.0	3.75	4840	1.89	37.6	0.023	3.30	nd	nd	nd	1.0	13.3
E14*	7510	nd	3.16	28.60	nd	0.20	14.0	6.92	7510	3.29	76.0	0.015	6.36	nd	nd	nd	0.8	23.3
E11*	7650	nd	2.28	30.80	nd	0.15	14.1	6.92	7650	3.76	77.7	0.019	6.29	nd	nd	nd	0.9	24.0
E8	8400	nd	2.28	31.20	nd	0.14	14.3	6.52	9930	3.81	82.7	0.022	6.01	nd	nd	nd	0.8	24.1
E5	9230	nd	2.71	37.60	nd	0.14	15.7	7.66	11,600	4.25	90.8	0.022	6.76	nd	nd	nd	0.8	27.3
E2	11,500	nd	2.24	69.40	nd	0.12	18.8	12.30	15,100	6.04	117.0	0.041	7.75	nd	nd	nd	1.0	35.3
116-m Depth Contour																		
B10	6700	<MDL	2.58	27.70	nd	0.14	18.5	5.79	13,200	4.17	67.8	0.019	6.36	nd	nd	nd	1.1	32.4
E21	6750	nd	1.86	30.40	nd	0.12	14.4	8.93	9550	4.18	73.2	0.024	6.87	nd	nd	nd	1.0	27.0
E15*	7220	nd	1.42	28.70	nd	0.13	15.3	7.96	9940	3.96	74.3	0.018	6.92	nd	nd	nd	1.5	27.8
E9	9100	nd	0.78	32.30	nd	0.18	19.0	10.90	13,400	4.78	83.4	0.022	7.29	nd	nd	nd	0.9	35.8
E3	8480	nd	2.02	51.90	nd	0.10	13.0	11.30	11,500	6.64	93.6	0.048	5.02	nd	nd	nd	0.7	30.2
Detection Rate (%)	100	14	100	100	0	95	100	100	100	100	100	100	100	0	0	0	100	100
ERL	na	na	8.2	na	na	1.2	81	34	na	46.7	na	0.15	20.9	na	1	na	na	150
ERM	na	na	70	na	na	9.6	370	270	na	218	na	0.71	51.6	na	3.7	na	na	410

na = not available; nd = not detected; <MDL=Average of lab duplicates below MDL (see City of San Diego 2011)

Appendix C.7 *continued*

Concentrations of trace metals (ppm) for the July 2010 PLOO survey. * = nearfield stations; ERL = Effects Range Low threshold value; ERM = Effects Range Median threshold value. See Appendix C.2 for MDLs and names for each metal represented by periodic table symbol.

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
88-m Depth Contour																		
B11	9750	0.62	4.00	66.60	nd	0.06	32.8	16.30	21,800	13.30	112.0	0.041	10.60	0.590	nd	nd	1.2	45.3
B8	9990	0.72	3.41	68.20	0.25	nd	25.3	16.00	14,700	12.00	103.0	0.038	9.49	nd	nd	nd	1.1	36.2
E19	9200	0.44	3.60	54.10	0.19	0.19	18.4	10.30	12,600	5.74	110.0	0.037	9.28	nd	nd	nd	1.1	33.9
E7	6910	0.37	2.99	43.40	0.15	0.16	14.7	8.50	9970	4.94	86.7	0.022	7.31	<MDL	0.17	nd	1.0	28.8
E1	8540	0.47	3.02	46.60	0.17	0.15	15.8	9.65	11,300	5.90	93.2	0.026	7.10	<MDL	nd	nd	1.1	29.1
98-m Depth Contour																		
B12	5970	0.42	5.45	22.00	0.06	nd	32.9	5.37	21,200	8.45	53.4	0.018	6.23	0.370	0.57	nd	0.6	35.5
B9	9820	nd	4.42	56.50	0.33	0.18	26.2	8.58	20,900	6.12	107.0	0.026	8.85	nd	nd	nd	1.3	40.9
E26	6610	nd	2.49	37.00	0.16	0.10	15.1	7.78	10,700	4.08	79.7	0.028	7.40	0.770	nd	nd	0.7	27.9
E25	6460	0.33	2.50	35.30	0.16	0.12	15.0	7.75	10,700	4.29	78.4	0.028	6.94	nd	nd	nd	0.8	27.0
E23	5140	nd	2.72	34.20	0.14	0.11	13.3	7.28	9130	4.40	70.8	0.040	6.86	0.420	nd	nd	0.7	25.0
E20	4420	nd	2.87	28.00	0.12	0.09	11.6	6.05	7980	3.79	59.9	0.023	5.74	nd	nd	nd	0.6	21.7
E17*	6120	nd	2.88	31.10	0.13	0.17	13.5	6.68	8930	3.66	72.3	0.019	6.33	nd	nd	nd	0.9	24.1
E14*	7100	0.47	6.11	35.40	0.15	0.25	15.3	12.30	12,000	3.51	141.0	0.022	9.70	0.290	nd	nd	1.0	35.0
E11*	5780	0.36	2.30	30.40	0.13	0.19	12.8	6.77	8710	3.43	68.4	0.022	6.20	0.310	0.05	nd	0.9	24.3
E8	7130	0.37	2.28	37.10	0.16	0.18	15.0	11.10	10,200	4.36	82.4	0.028	6.99	<MDL	nd	nd	1.2	27.7
E5	6400	0.33	2.34	41.10	0.14	0.15	13.5	7.35	9400	4.09	75.2	0.017	6.25	<MDL	nd	nd	0.9	25.0
E2	9310	0.38	2.79	54.80	0.18	0.15	17.2	11.70	12,800	5.69	103.0	0.028	7.64	<MDL	nd	nd	1.1	33.8
116-m Depth Contour																		
B10	6920	nd	3.20	29.80	0.18	0.19	16.9	6.16	12,200	3.66	72.8	0.018	6.02	0.320	nd	nd	0.8	28.3
E21	5860	0.32	2.72	32.20	0.14	0.17	14.9	6.48	10,300	4.14	72.0	0.024	7.08	0.620	nd	nd	0.7	26.5
E15*	6000	nd	2.15	28.80	0.13	0.16	13.1	6.62	8490	3.58	67.9	0.024	5.97	nd	nd	nd	1.0	22.8
E9	6860	0.48	3.09	31.20	0.17	0.19	17.9	10.80	12,000	5.08	73.0	0.044	6.82	<MDL	nd	nd	1.0	36.6
E3	6270	0.39	2.58	50.20	0.13	0.13	13.1	12.20	10,400	7.42	91.2	0.025	5.22	<MDL	0.10	nd	0.9	31.8
Detection Rate (%)	100	68	100	100	95	91	100	100	100	100	100	100	100	36	18	0	100	100
ERL	na	na	8.2	na	na	1.2	81	34	na	46.7	na	0.15	20.9	na	1	na	na	150
ERM	na	na	70	na	na	9.6	370	270	na	218	na	0.71	51.6	na	3.7	na	na	410

na = not available; nd = not detected; <MDL=Average of lab duplicates below MDL (see City of San Diego 2011)

Appendix C.8

Concentrations of HCH - Beta isomer (HCH), HCB, tDDT, tPCB, and tPAH detected at each PLOO benthic station during the January and July 2010 surveys. * = nearfield stations; DR = detection rate; ERL = Effects Range Low threshold value; ERM = Effects Range Median threshold value.

	January						July				
	HCH (ppt)	HCB (ppt)	tDDT (ppt)	tPCB (ppt)	tPAH (ppb)		HCH (ppt)	HCB (ppt)	tDDT (ppt)	tPCB (ppt)	tPAH (ppb)
88-m Depth Contour						*88-m Depth Contour*					
B11	nd	76	220	nd	nd	B11	980	nd	nd	nd	nd
B8	nd	nd	330	nd	nd	B8	nd	nd	260	nd	nd
E19	nd	nd	600	nd	nd	E19	nd	nd	230	nd	nd
E7	nd	nd	530	53	nd	E7	nd	nd	220	nd	nd
E1	nd	nd	760	5450	294.4	E1	nd	nd	470	1791	21.2
98-m Depth Contour						*98-m Depth Contour*					
B12	nd	160	250	nd	nd	B12	nd	nd	<MDL	nd	nd
B9	nd	nd	580	nd	nd	B9	nd	nd	12,290	nd	nd
E26	nd	nd	450	nd	nd	E26	nd	nd	280	nd	nd
E25	nd	nd	370	nd	nd	E25	nd	nd	380	nd	nd
E23	nd	nd	420	155	nd	E23	nd	nd	250	nd	nd
E20	nd	nd	240	nd	nd	E20	nd	nd	280	nd	nd
E17*	nd	200	210	83	nd	E17*	nd	nd	250	2030	nd
E14*	nd	nd	190	nd	nd	E14*	nd	nd	160	nd	nd
E11*	nd	nd	290	nd	nd	E11*	nd	nd	210	nd	nd
E8	nd	nd	nd	<MDL	nd	E8	nd	nd	190	150	nd
E5	nd	220	350	83	nd	E5	nd	nd	230	nd	nd
E2	nd	140	1870	1479	83.4	E2	nd	nd	270	nd	nd
116-m Depth Contour						*116-m Depth Contour*					
B10	nd	nd	310	nd	nd	B10	nd	nd	230	nd	nd
E21	nd	nd	370	7070	nd	E21	nd	nd	300	nd	nd
E15*	nd	nd	310	nd	nd	E15*	nd	nd	210	nd	nd
E9	nd	nd	190	803	nd	E9	nd	nd	230	nd	nd
E3	nd	160	210	738	81.1	E3	nd	nd	240	1900	20.4
DR (%)	0	27	95	41	14	DR (%)	5	0	91	18	9
ERL	na	na	1580	na	4022	ERL	na	na	1580	na	4022
ERM	na	na	46,100	na	44,792	ERM	na	na	46,100	na	44,792

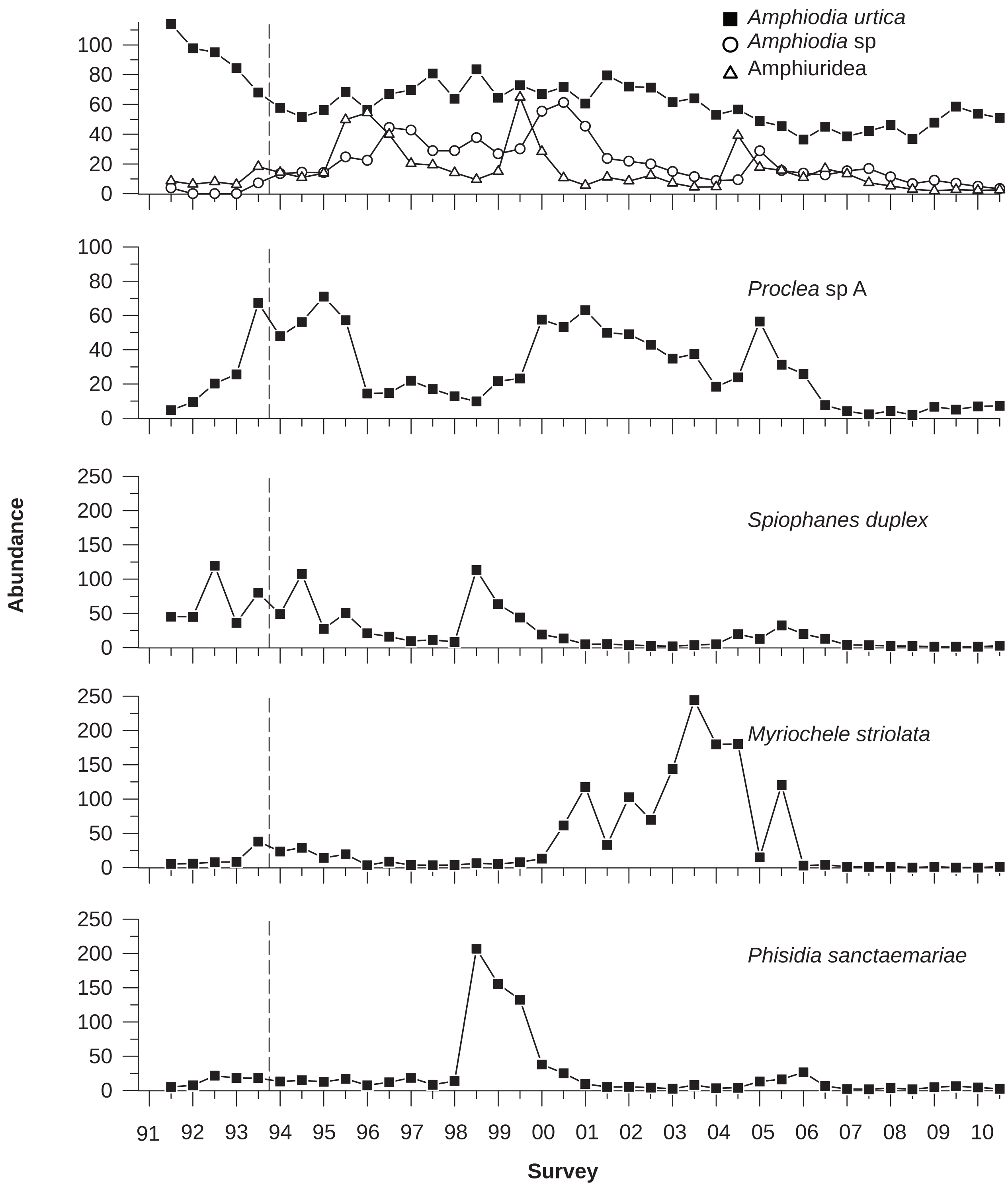
na = not available; nd = not detected; <MDL=Average of lab duplicates below MDL (see City of San Diego 2011)

Appendix D

Supporting Data

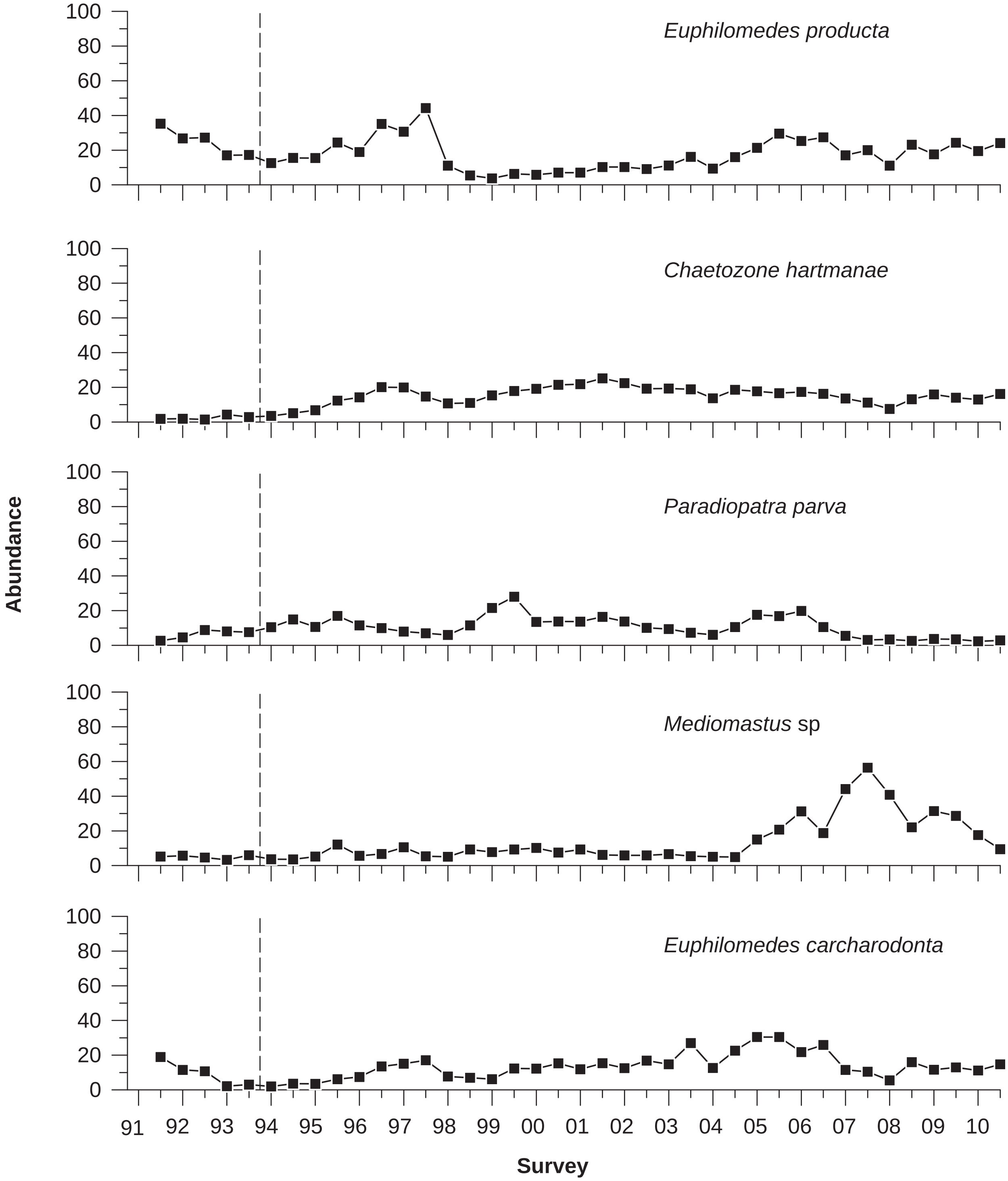
2010 PLOO Stations

Macrobenthic Communities



Appendix D.1

Abundance per survey for each of the 10 most abundant species (taxa) at PLOO benthic stations sampled between 1991 and 2010. Species listed in order of decreasing abundance. *Amphiodia urtica* and unidentifiable juveniles (*Amphiodia* sp and Amphiuridea) graphed together; note expanded scale for *Spiophanes duplex*, *Myriochele striolata*, and *Phisidia sanctaemariae*. Data are expressed as mean values of biannual (i.e., first and third quarters) samples during each survey ($n=22$); sampling was limited to primary core stations ($n=12$) during the quarters 03-3, 04-3, 05-1, 08-3, and 09-1 due to regulatory relief to accommodate special projects. Dashed lines indicate onset of discharge from the PLOO.



Appendix D.1 *continued*

Appendix D.2

Abundance (# individuals/0.1-m^2) of common organisms within groups defined by cluster analysis (Figure 5.4). Data are expressed as means ±SE. Colored boxes provide partial explanation of SIMPROF support for each clade. Gray shaded boxes show abundances of select invertebrates that occurred ubiquitously across the PLOO sampling region. Blue shaded boxes indicate the absence of many common taxa from one grab at site E21 in January (cluster group E). Pink boxes indicate high abundances of select organisms at deep sites B12, E3, and E9 (cluster group D). Yellow boxes highlight select species whose abundances at the PLOO (site E14) site differed from other survey sites (cluster group A). Green boxes show high populations of the ophiuroid *Amphiodia urtica* at mid-depth sites.

	E14 Jan (1 grab), Jul	B10 Jul	B11	B10 Jan	B9	E9 Jul	E2	E14 Jan (1 grab)	E5, E7, E8, E11, E15, E17, E19, E20, E23, E25, E26, E21 Jan (1 grab), Jul	B8	E1	E21 Jan (1 grab)	B12	E3 Jul	E3 Jan, E9 Jan
Cluster Group	**A**	**B**	**C**	**F**	**F**	**F**	**F**	**F**	**F**	**G**	**G**	**E**	**D**	**D**	**D**
Number of Grabs	3	2	4	2	4	2	4	1	47	4	4	1	4	2	4
Annelida (Polychaeta)															
Aphelochaeta glandaria Cmplx	18.33	28.5	1.75	10	1.5	2	1	4	7.04	0.75	1.25	3	3	6	6
	(9.96)	(0.5)	(1.03)	(4)	(0.29)	(1)	(1)		(0.79)	(0.48)	(0.48)		(1.08)	(1)	(1.15)
Aphelochaeta sp LA1	2	6	8.5	5.5	2	3.5	7.75	1	2.34	0.25	2.75	1	4.5	5	5
	(0.58)	(2)	(2.10)	(1.5)	(1.68)	(1.5)	(2.25)		(0.40)	(0.25)	(0.63)		(2.22)	(1)	(1.83)
Aricidea (Acmira) catherinae	3	2.5	1.75	13.5	6.5	39.5	12.5	36	8.53	0.25	2	1	8	5	2
	(0.58)	(2.5)	(1.03)	(2.5)	(1.5)	(18.5)	(3.77)		(1.19)	(0.25)	(0.41)		(4.71)	(1)	(1.35)
Chaetozone hartmanae	13	5.5	14.25	8.5	14.5	8.5	7	15	7.60	1	1	4	2	1	2
	(3.21	(1.5)	(2.10)	(5.5)	(2.60)	(2.5)	(1.22)		(0.84)	(0.41)	(0.71)		(0.71)	(0)	(1.22)
Lumbrineris sp Group I	2	1	0.25	0.5	4	10.5	12.25	9	5.68	1	3.5	7	0.25	2.5	1.75
	(0.58)	(0)	(0.25)	(0.5)	(1)	(0.5)	(2.25)		(0.83)	(0.58)	(1.44)		(0.25)	(2.5)	(0.85)
Lysippe sp A	2.67	0.5	3.25	3	3.5	18.5	6.5	5	4.79	1.75	2.75	7	7	14.5	6.5
	(1.45)	(0.5)	(1.31)	(2)	(0.96)	(3.5)	(1.55)		(0.50)	(1.03)	(0.75)		(3.19	(4.5)	(0.87)
Prionospio (Prionospio) jubata	1.33	6.5	2.25	1.5	1.5	1.5	2.25	2	2.98	7	0.75	3	3.75	3	3.25
	(0.88)	(0.5)	(0.63)	(0.5)	(0.65)	(0.5)	(1.03)		(0.32)	(6.04)	(0.75)		(2.14)	(2)	(0.85)
Sternaspis fossor	1	3	4	8.5	2.5	3	2	6	5.36	3.5	4	6	0.75	1	3
	(0.58)	(1)	(1.91)	(2.5)	(0.87)	(0)	(0.41)		(0.41)	(1.55)	(1.08)		(0.48)	(0)	(0.82)
Arthropoda															
Caecognathia crenulatifrons	2	4	1.5	6	5	2	1.25	5	4.32	1	1	1	4.5	4	0.75
	(1.15)	(2)	(0.65)	(3)	(1.47)	(0)	(0.75)		(0.56)	(0.41)	(0.41)		(0.5)	(2)	(0.25)
Annelida (Polychaeta)															
Aphelochaeta monilaris	10	11.5	2.25	22.5	1.5	3	3	2	2.87	0.75	1.5	0	1.25	2.5	0.5
	(1.53)	(1.5)	(0.25)	(1.5)	(0.65)	(2)	(1.35)	(2)	(0.42)	(0.48)	(0.65)		(0.25)	(1.5)	(0.29)
Clymenura gracilis	2	0.5	3	1	3.5	1.5	5.25	1	3.19	5	5.25	0	0.75	2	2.75
	(1.15)	(0.5)	(0.71)	(1)	(0.65)	(1.5)	(1.38)		(0.35)	(1.58)	(0.48)		(0.48)	(0)	(1.03)
Prionospio (Prionospio) dubia	4	1	5	4	2.25	4	9.5	2	4.62	5.5	3.5	0	3.25	5.5	4
	(0.58)	(1)	(1.35)	(0)	(0.48)	(2)	(1.19)		(0.48)	(1.55)	(1.26)		(1.03)	(0.5)	(0.82)
Arthropoda															
Ampelisca pugetica	2	2	6	1	3.75	2	0.75	3	1.43	0.75	0.5	0	2.25	3	1
	(0)	(1)	(1.78)	(1)	(1.93)	(1)	(0.75)		(0.20)	(0.25)	(0.29)		(1.03)	(1)	(0.41)

Appendix D.2 *continued*

Mollusca															
Axinopsida serricata	6.67 (3.53)	15.5 (1.5)	31.5 (6.08)	39 (1)	23.5 (4.73)	0.5 (0.5)	1.5 (0.29)	15	9 (2.14)	28.25 (10.19)	1.5 (0.5)	0	9.75 (4.01)	1 (0)	1 (0.41)
Ennucula tenuis	0.33 (0.33)	1.5 (1.5)	6 (1.15)	1.5 (1.5)	1.5 (0.87)	4.5 (2.5)	7.5 (0.32)	2	3.40 (0.37)	4.25 (1.49)	11.25 (1.03)	0	0.25 (0.25)	3 (1)	2.75 (1.44)
Annelida (Polychaeta)															
Aricidea (Acmira) lopezi	0	0	0.25 (0.25)	0	1.25 (1.25)	1 (1)	0	0	5.09 (1.03)	0.25 (0.25)	2.25 (1.44)	0	3.75 (1.89)	0	14.75 (4.82)
Mollusca															
Micranellum crebricinctum	0	0	0	0	0	0	0	0	0	0	0	0	13.75 (1.49)	1.5 (1.5)	2.5 (1.5)
Annelida (Polychaeta)															
Capitella teleta	15.33 (3.28)	0	0.25 (0.25)	0	0	0	0.25 (0.25)	26	0.36 (0.12)	0	0	0	0.25 (0.25)	0	0
Notomastus sp A	27.33 (7.31)	1.5 (1.5)	1 (0.41)	0.5 (0.5)	0	1.5 (0.5)	1 (0.71)	0	0.26 (0.07)	0	0.25 (0.25)	0	0.75 (0.48)	1 (0)	1.25 (0.48)
Polycirrus californicus	0	0	0	0	0	0	0	0	0.28 (0.19)	0	0	0	0	0	0.25 (0.25)
Polycirrus sp A	6 (4.16)	0	4.25 (0.63)	36.5 (12.5)	12.25 (2.72)	1.5 (0.5)	9.25 (1.75)	32	10.72 (1.44)	2.25 (1.11)	5.25 (0.95)	8	7.25 (3.86)	13 (1)	6.25 (1.44)
Polycirrus sp I	0	0	0.5 (0.5)	1.5 (0.5)	0	0.5 (0.5)	0	0	0.13 (0.05)	0	0	0	0.25 (0.25)	0	0
Polycirrus sp OC1	6.3 (0.88)	8.5 (8.5)	0.75 (0.75)	0	0	0	0	0	2.50 (0.99)	0	0.5 (0.5)	0	0.25 (0.25)	1 (1)	0.25 (0.25)
Polycirrus sp	40.33 (19.80)	9 (1)	4.75 (0.85)	0	2.25 (1.44)	16.5 (3.5)	9.5 (5.74)	8	2.83 (0.69)	1 (0.58)	0.25 (0.25)	0	5.5 (4.01)	1 (0)	0
Arthropoda															
Ampelisca pacifica	1.33 (0.88)	5.5 (2.5)	3 (1.22)	3.5 (0.5)	5 (0.71)	4.5 (1.5)	3.25 (1.44)	0	4.81 (0.52)	7 (2.12)	2.75 (0.85)	2	2 (0.41)	3 (0)	3.25 (0.75)
Eyakia robusta	0	2 (0)	1.5 (0.65)	2 (2)	4 (0.41)	3 (0)	1.75 (0.25)	0	1.51 (0.27)	4.25 (0.95)	2 (1.22)	0	1.75 (0.63)	1 (0)	1.5 (0.29)
Echinodermata															
Amphiodia digitata	0	3 (2)	0.25 (0.25)	2 (0)	0.75 (0.48)	9.5 (0.5)	1.25 (0.48)	0	0.40 (0.10)	0.25 (0.25)	0.25 (0.25)	0	8.25 (2.56)	15.5 (5.5)	12.25 (2.02)
Amphiodia urtica	0	1.5 (0.5)	4.75 (1.44)	3.5 (0.5)	15.75 (2.43)	7.5 (1.5)	42.5 (3.77)	8	27.89 (2.11)	56.25 (5.31)	95.75 (4.48)	14	1.75 (1.03)	5.5 (1.5)	4.5 (2.53)

Appendix D.3

Summary of taxa that distinguish between cluster groups according to SIMPER analysis. Shown are the five taxa with the greatest percent contribution to overall average Bray-Curtis dissimilarity between each group.

Species/Taxa	Average Dissimilarity/ Standard Deviation	Percent Contribution	Cumulative Percent Contribution
Groups A & B			
Notomastus sp A	0.37	1.68	1.68
Capitella teleta	0.18	1.54	3.23
Polycirrus sp	0.37	1.52	4.75
Euclymeninae	0.24	1.36	6.11
Euclymeninae sp A	0.09	1.26	7.37
Groups A & C			
Adontorhina cyclia	0.20	1.79	1.79
Decamastus gracilis	0.39	1.72	3.51
Notomastus sp A	0.33	1.72	5.23
Polycirrus sp	0.56	1.65	6.88
Chloeia pinnata	0.62	1.5	8.38
Groups A & D			
Polycirrus sp	0.84	1.95	1.95
Notomastus sp A	0.34	1.7	3.65
Capitella teleta	0.19	1.49	5.14
Euclymeninae	0.23	1.47	6.61
Chloeia pinnata	0.59	1.35	7.96
Groups A & E			
Polycirrus sp	1.30	2.41	2.41
Notomastus sp A	0.42	2.26	4.66
Chloeia pinnata	1.23	1.78	6.44
Decamastus gracilis	0.52	1.75	8.19
Euclymeninae	0.29	1.73	9.92
Groups A & F			
Amphiodia urtica	0.41	1.97	1.97
Notomastus sp A	0.32	1.92	3.89
Polycirrus sp	0.77	1.87	5.76
Decamastus gracilis	0.45	1.55	7.3
Chloeia pinnata	0.68	1.47	8.78
Groups A & G			
Amphiodia urtica	0.44	3.49	3.49
Polycirrus sp	0.97	2.03	5.51
Notomastus sp A	0.34	2.01	7.52
Decamastus gracilis	0.41	1.94	9.47
Chloeia pinnata	0.90	1.61	11.07
Groups B & C			
Aphelochaeta glandaria Cmplx	0.30	2.01	2.01

Appendix D.3 *continued*

Species/Taxa	Average Dissimilarity/ Standard Deviation	Percent Contribution	Cumulative Percent Contribution
Groups B & C			
Adontorhina cyclia	0.25	1.56	3.57
Aricidea (*Acmira*) *rubra*	0.04	1.51	5.08
Chaetozone sp SD5	0.08	1.33	6.41
Polycirrus sp A	0.08	0.93	7.34
Groups B & D			
Aricidea (*Acmira*) *rubra*	0.04	1.71	1.71
Aphelochaeta glandaria Cmplx	0.24	1.69	3.4
Polycirrus sp A	0.38	1.34	4.74
Aphelochaeta monilaris	0.20	1.26	6
Polycirrus sp	0.30	1.25	7.24
Groups B & E			
Axinopsida serricata	0.02	2.21	2.21
Aphelochaeta glandaria Cmplx	0.09	2.03	4.25
Aphelochaeta monilaris	0.02	1.9	6.15
Aricidea (*Acmira*) *rubra*	0.02	1.86	8.01
Polycirrus sp	0.20	1.7	9.71
Groups B & F			
Amphiodia urtica	0.49	1.93	1.93
Aphelochaeta glandaria Cmplx	0.42	1.65	3.58
Aricidea (*Acmira*) *rubra*	0.20	1.6	5.18
Polycirrus sp A	0.52	1.52	6.71
Chaetozone sp SD5	0.11	1.49	8.19
Groups B & G			
Amphiodia urtica	0.57	3.77	3.77
Aphelochaeta glandaria Cmplx	0.26	2.31	6.08
Aricidea (*Acmira*) *rubra*	0.04	1.67	7.75
Chaetozone sp SD5	0.09	1.48	9.23
Chloeia pinnata	0.12	1.41	10.63
Groups C & D			
Adontorhina cyclia	0.33	2.03	2.03
Axinopsida serricata	0.53	1.9	3.93
Amphiodia digitata	0.32	1.47	5.4
Chaetozone hartmanae	0.28	1.28	6.68
Euphilomedes producta	0.33	1.05	7.73
Groups C & E			
Axinopsida serricata	0.49	3.02	3.02
Adontorhina cyclia	0.32	2.6	5.62
Ennucula tenuis	0.19	1.31	6.93

Appendix D.3 *continued*

Species/Taxa	Average Dissimilarity/ Standard Deviation	Percent Contribution	Cumulative Percent Contribution
Groups C & E			
Lumbrineris sp Group I	0.19	1.3	8.23
Ampelisca pugetica	0.31	1.3	9.53
Groups C & F			
Adontorhina cyclia	0.51	1.81	1.81
Axinopsida serricata	0.56	1.73	3.54
Euphilomedes producta	0.43	1.57	5.11
Amphiodia urtica	0.48	1.46	6.57
Aricidea (*Acmira*) *catherinae*	0.47	1.05	7.62
Groups C & G			
Amphiodia urtica	0.56	3.56	3.56
Axinopsida serricata	0.65	1.7	5.26
Chaetozone hartmanae	0.29	1.61	6.86
Adontorhina cyclia	0.75	1.4	8.26
Rhepoxynius bicuspidatus	0.18	1.06	9.33
Groups D & E			
Amphiodia digitata	0.44	2.08	2.08
Amphiodia urtica	0.53	1.42	3.5
Aricidea (*Acmira*) *lopezi*	0.79	1.36	4.86
Micranellum crebricinctum	0.70	1.33	6.19
Chloeia pinnata	0.74	1.25	7.44
Groups D & F			
Amphiodia urtica	0.61	1.95	1.95
Amphiodia digitata	0.39	1.57	3.52
Micranellum crebricinctum	0.52	1.18	4.7
Monticellina siblina	0.63	1.17	5.86
Aricidea (*Acmira*) *lopezi*	0.52	1.11	6.97
Groups D & G			
Amphiodia urtica	0.71	4.09	4.09
Amphiodia digitata	0.41	1.72	5.81
Monticellina siblina	0.73	1.4	7.21
Adontorhina cyclia	0.73	1.34	8.55
Axinopsida serricata	0.74	1.29	9.84
Groups E & F			
Axinopsida serricata	0.92	1.83	1.83
Prionospio (*Prionospio*) *dubia*	0.39	1.49	3.32
Praxillella pacifica	0.53	1.47	4.79
Aricidea (*Acmira*) *catherinae*	0.58	1.46	6.25
Lumbrineris cruzensis	0.73	1.3	7.55

Appendix D.3 *continued*

Species/Taxa	Average Dissimilarity/ Standard Deviation	Percent Contribution	Cumulative Percent Contribution
Groups E & G			
Amphiodia urtica	0.77	3.95	3.95
Axinopsida serricata	1.26	2.4	6.34
Ennucula tenuis	0.51	2.14	8.48
Mediomastus sp	0.43	2.1	10.59
Adontorhina cyclia	1.24	1.94	12.53
Groups F & G			
Amphiodia urtica	0.71	2.52	2.52
Euphilomedes producta	0.54	2	4.52
Axinopsida serricata	0.75	1.67	6.19
Adontorhina cyclia	0.73	1.57	7.76
Euphilomedes carcharodonta	0.52	1.46	9.22

Appendix E

Supporting Data

2010 PLOO Stations

Demersal Fishes and Megabenthic Invertebrates

Appendix E.1

Summary of demersal fish species captured during 2010 at PLOO trawl stations. Data are number of fish (*n*), biomass (BM; kg, wet weight), minimum, maximum, and mean length (cm, standard length). Taxonomic arrangement and scientific names are of Eschmeyer and Herald (1998) and Allen (2005).

				Length		
Taxon/Species	**Common name**	***n***	**BM**	**Min**	**Max**	**Mean**
RAJIFORMES						
Rajidae						
Raja inornata	California skate	16	5.70	12	54	29
Raja rhina	Longnose skate	1	0.10	19	19	19
AULOPIFORMES						
Synodontidae						
Synodus lucioceps	California lizardfish	961	13.80	8	24	12
OPHIDIIFORMES						
Ophidiidae						
Chilara taylori	Spotted cuskeel	4	0.30	10	15	13
BATRACHOIDIFORMES						
Batrachoididae						
Porichthys notatus	Plainfin midshipman	68	2.00	6	19	11
SCORPAENIFORMES						
Scorpaenidae						
Scorpaena guttata	California scorpionfish	23	6.20	15	24	19
Sebastes chlorostictus	Greenspotted rockfish	2	0.10	10	11	11
Sebastes elongatus	Greenstriped rockfish	26	0.90	4	15	7
Sebastes helvomaculatus	Rosethorn rockfish	1	0.10	7	7	7
Sebastes saxicola	Stripetail rockfish	124	2.00	5	12	8
Sebastes semicinctus	Halfbanded rockfish	140	3.30	4	13	10
Hexagrammidae						
Zaniolepis frenata	Shortspine combfish	75	2.10	8	17	12
Zaniolepis latipinnis	Longspine combfish	343	4.10	6	15	9
Cottidae						
Chitonotus pugetensis	Roughback sculpin	51	0.90	1	11	8
Icelinus quadriseriatus	Yellowchin sculpin	902	4.40	3	8	6
Icelinus tenuis	Spotfin sculpin	3	0.10	9	9	9
PERCIFORMES						
Embiotocidae						
Zalembius rosaceus	Pink seaperch	34	1.20	4	12	8
Zoarcidae						
Lycodes pacificus	Blackbelly eelpout	9	0.30	14	23	19
Agonidae						
Xeneretmus latifrons	Blacktip poacher	2	0.20	14	17	16
PLEURONECTIFORMES						
Paralichthyidae						
Citharichthys sordidus	Pacific sanddab	2290	23.9	3	25	7
Citharichthys xanthostigma	Longfin sanddab	14	1.00	12	20	15
Hippoglossina stomata	Bigmouth sole	17	2.10	15	22	18
Pleuronectidae						
Eopsetta exilis	Slender sole	16	0.70	13	16	14
Microstomus pacificus	Dover sole	216	5.90	5	22	11
Parophrys vetulus	English sole	69	6.00	10	24	15

Appendix E.1 *continued*

Taxon/Species	Common name	*n*	Bm	Length Min	Max	Mean
Pleuronichthys verticalis	Hornyhead turbot	11	1.50	11	19	16
Cynoglossidae						
Symphurus atricauda	California tonguefish	32	1.00	9	16	14

Appendix E.2

Summary of total abundance by species and station for demersal fishes at the PLOO trawl stations during 2010.

	January 2010						
Name	SD7	SD8	SD10	SD12	SD13	SD14	Species Abundance by Survey
Yellowchin sculpin	193	82	225	145	109	116	870
Pacific sanddab	115	70	192	93	43	37	550
California lizardfish	14	93	37	32	98	226	500
Longspine combfish	29	4	49	68	85	44	279
Dover sole		3		71	1		75
Stripetail rockfish		16	14	18	7	6	61
English sole	1	4	14	8	17	11	55
Roughback sculpin	21	12	11		2	3	49
Plainfin midshipman	17	8	9	4	2	2	42
Halfbanded rockfish	1	6	3	4	1	23	38
Shortspine combfish	6	14	1	9		1	31
California tonguefish	10	12	2	1	2		27
California scorpionfish	1	1	3	12	4	2	23
Pink seaperch	5	6	6	1	3	2	23
Longfin sanddab					8	6	14
Bigmouth sole	2		1	1	3	1	8
Greenstriped rockfish	1	2		2	1		6
Hornyhead turbot	3			2		1	6
California skate		3			1	1	5
Blacktip poacher		1					1
Winter Total	419	337	567	471	387	482	2663

Appendix E.2 *continued*

Name	July 2010						Species Abundance by Survey
	SD7	SD8	SD10	SD12	SD13	SD14	
Pacific sanddab	295	354	238	158	400	295	1740
California lizardfish	38	66	62	222	50	23	461
Dover sole	12	17	36	55	11	10	141
Halfbanded rockfish	5	21	16	8	48	4	102
Longspine combfish	15	8	6	16	11	8	64
Stripetail rockfish			14	15	25	9	63
Shortspine combfish	5	10	5	18	3	3	44
Yellowchin sculpin	6		18		8		32
Plainfin midshipman	2	5	4	3	9	3	26
Greenstriped rockfish		5	3	10	1	1	20
Slender sole				7	1	8	16
English sole			3	1	2	8	14
California skate			2	3	4	2	11
Pink seaperch	1	1	2	3	2	2	11
Bigmouth sole		1	1	2	3	2	9
Blackbelly eelpout			1	3		5	9
California tonguefish		1	4				5
Hornyhead turbot	1		1		1	2	5
Spotted cusk eel	1	1	2				4
Spotfin sculpin		3					3
Greenspotted rockfish						2	2
Roughback sculpin	1		1				2
Blacktip poacher						1	1
Longnose skate	1						1
Rosethorn rockfish		1					1
Summer Total	383	494	419	524	579	388	2787

Appendix E.3

Summary of biomass (kg) by species and station for demersal fishes at the PLOO trawl stations during 2010.

	January 2010						
Name	**SD7**	**SD8**	**SD10**	**SD12**	**SD13**	**SD14**	**Biomass by Survey**
Pacific sanddab	1.5	2.0	3.7	1.5	1.2	0.8	10.7
California lizardfish	0.3	1.3	0.5	0.6	1.2	3.3	7.2
California scorpionfish	0.2	0.3	0.7	3.7	1.0	0.3	6.2
English sole	0.1	0.5	1.0	0.5	1.5	0.9	4.5
Yellowchin sculpin	0.9	0.4	1.0	0.8	0.5	0.5	4.1
Longspine combfish	0.7	0.1	1.0	0.4	0.5	0.3	3.0
California skate		1.0			0.1	0.1	1.2
Dover sole		0.1		1.0	0.1		1.2
Longfin sanddab					0.5	0.5	1.0
Halfbanded rockfish	0.1	0.1	0.1	0.1	0.1	0.5	1.0
Bigmouth sole	0.1		0.1	0.1	0.5	0.1	0.9
Plainfin midshipman	0.1	0.1	0.3	0.1	0.1	0.1	0.8
Roughback sculpin	0.3	0.1	0.1		0.1	0.1	0.7
California tonguefish	0.2	0.2	0.1	0.1	0.1		0.7
Hornyhead turbot	0.4			0.2		0.1	0.7
Shortspine combfish	0.1	0.2	0.1	0.2		0.1	0.7
Stripetail rockfish		0.2	0.2	0.1	0.1	0.1	0.7
Pink seaperch	0.1	0.1	0.1	0.1	0.1	0.1	0.6
Greenstriped rockfish	0.1	0.1		0.1	0.1		0.4
Blacktip poacher		0.1					0.1
Winter Total	5.2	6.9	9.0	9.6	7.8	7.9	46.4

Appendix E.3 *continued*

Name	July 2010						Biomass by Survey
	SD7	SD8	SD10	SD12	SD13	SD14	
Pacific sanddab	1.4	1.6	4.0	1.6	2.3	2.3	13.2
California lizardfish	1.0	0.4	1.1	2.9	0.7	0.5	6.6
Dover sole	0.9	0.6	1.0	0.7	0.7	0.8	4.7
California skate			1.0	3.0	0.2	0.3	4.5
Halfbanded rockfish	0.2	0.5	0.4	0.2	0.9	0.1	2.3
English sole			0.4	0.2	0.2	0.7	1.5
Shortspine combfish	0.2	0.3	0.2	0.4	0.1	0.2	1.4
Stripetail rockfish			0.3	0.3	0.5	0.2	1.3
Bigmouth sole		0.1	0.2	0.3	0.4	0.2	1.2
Plainfin midshipman	0.1	0.2	0.2	0.2	0.3	0.2	1.2
Longspine combfish	0.3	0.1	0.1	0.2	0.2	0.2	1.1
Hornyhead turbot	0.1		0.2		0.1	0.4	0.8
Slender sole				0.3	0.1	0.3	0.7
Pink seaperch	0.1	0.1	0.1	0.1	0.1	0.1	0.6
Greenstriped rockfish		0.1	0.1	0.1	0.1	0.1	0.5
Blackbelly eelpout			0.1	0.1		0.1	0.3
California tonguefish		0.1	0.2				0.3
Spotted cusk eel	0.1	0.1	0.1				0.3
Yellowchin sculpin	0.1		0.1		0.1		0.3
Roughback sculpin	0.1		0.1				0.2
Blacktip poacher						0.1	0.1
Greenspotted rockfish						0.1	0.1
Longnose skate	0.1						0.1
Rosethorn rockfish		0.1					0.1
Spotfin sculpin		0.1					0.1
Summer Total	4.7	4.4	9.9	10.6	7.0	6.9	43.5

Appendix E.4

Summary of biomass (kg) of demersal fishes by species for north and south farfield PLOO trawl regions.

Species	North Farfield Av. Abundance	South Farfield Av. Abundance	Percent Contribution	Cumulative Percent Contribution
Pacific sanddab	223.87	129.97	11.69	11.69
Stripetail rockfish	16.39	1.55	6.86	18.55
Plainfin midshipman	17.58	2.66	5.87	24.42
Halfbanded rockfish	13.18	4.63	5.06	29.48
Dover sole	25.55	10.97	4.99	34.47
Yellowchin sculpin	11.87	8.08	4.78	39.25
Longspine combfish	10.53	2.63	4.42	43.67
Longfin sanddab	6.03	5.53	4.38	48.05
Shortspine combfish	1.16	5.45	3.71	51.76
California tonguefish	0.21	3.29	3.67	55.43
California lizardfish	4.21	3.84	3.47	58.90
Pink seaperch	5.21	1.50	3.30	62.20
Slender sole	3.63	1.45	3.04	65.25
Spotfin sculpin	0.03	2.84	3.03	68.27
English sole	2.37	0.87	2.33	70.61
Bay goby	1.76	0.82	2.27	72.87
Pacific argentine	0.68	1.82	2.11	74.98
Blackbelly eelpout	2.13	0.03	1.93	76.92
Greenblotched rockfish	0.95	0.66	1.73	78.65
Greenstriped rockfish	0.58	0.95	1.69	80.34
Roughback sculpin	0.11	0.82	1.60	81.94
Hornyhead turbot	0.61	0.37	1.37	83.30
Bigmouth sole	1.03	0.87	1.28	84.58
Spotted cuskeel	0.29	0.50	1.26	85.84
Gulf sanddab	0.95	0.21	1.21	87.05
Greenspotted rockfish	0.34	0.29	1.14	88.19
Pygmy poacher	0.37	0.21	0.92	89.11
Unidentified flatfish	0.61	0.05	0.89	90.00

Appendix E.5

Summary of biomass (kg) of demersal fishes by species for statistically distinct PLOO year groupings.

Species	1991–2002 Avg Abundance	2003–2010 Avg Abundance	Percent Contribution	Cumulative Percent Contribution
Longfin sanddab	2.13	0.08	5.95	5.95
Halfbanded rockfish	1.21	4.60	4.91	10.86
California lizardfish	0.21	1.89	4.19	15.05
Greenstriped rockfish	0.19	1.24	3.88	18.93
Bay goby	1.01	0.13	3.76	22.69
Slender sole	0.89	1.98	3.25	25.95
Shortspine combfish	0.87	2.58	3.23	29.17
Longspine combfish	1.66	3.08	2.89	32.06
Stripetail rockfish	2.30	1.25	2.83	34.90
Blackbelly eelpout	0.21	0.67	2.76	37.66
Yellowchin sculpin	2.45	1.38	2.54	40.20
Hornyhead turbot	0.15	0.71	2.44	42.64
Greenblotched rockfish	0.71	0.37	2.30	44.94
Pacific sanddab	11.99	13.24	2.27	47.21
English sole	0.60	1.40	2.18	49.39
Pacific argentine	0.46	0.15	2.15	51.54
Blacktip poacher	0.00	0.35	2.15	53.69
Plainfin midshipman	2.55	1.58	2.14	55.83
Pink seaperch	1.17	1.72	2.14	57.97
Greenspotted rockfish	0.36	0.05	2.09	60.06
Spotted cuskeel	0.23	0.56	1.97	62.03
Gulf sanddab	0.30	0.02	1.97	64.00
California skate	0.10	0.43	1.96	65.96
Spotfin sculpin	0.36	0.39	1.95	67.91
Dover sole	3.64	5.02	1.91	69.82
Roughback sculpin	0.25	0.43	1.85	71.66
California tonguefish	0.80	0.76	1.67	73.34
Unidentified rockfish	0.14	0.23	1.61	74.95
Pygmy poacher	0.06	0.26	1.58	76.53
Unidentified flatfish	0.20	0.14	1.54	78.07
Bigmouth sole	0.67	0.48	1.51	79.58
White croaker	0.10	0.19	1.49	81.07
Pink rockfish	0.00	0.21	1.43	82.50
Flag rockfish	0.19	0.08	1.38	83.88
Bluespotted poacher	0.07	0.16	1.30	85.18
Bigfin eelpout	0.04	0.20	1.29	86.47
California scorpionfish	0.12	0.04	1.10	87.58
Blue banded ronquil	0.08	0.06	1.03	88.61
Blackeye goby	0.06	0.08	0.98	89.59
Squarespot rockfish	0.11	0.04	0.95	90.54

Appendix E.6

Summary of the demersal fishes that distinguish between each cluster group according to SIMPER analysis. Shown are the five species with the greatest percent contribution to overall average Bray-Curtis dissimilarity between each group.

Species	Average Dissimilarity/ Standard Deviation	Percent Contribution	Cumulative Percent Contribution
Groups A & D			
Pacific sanddab	3.5	19.0	19.0
Stripetail rockfish	14.1	17.2	36.2
Yellowchin sculpin	3.0	8.9	45.1
Longfin sanddab	6.6	8.1	53.2
Plainfin midshipman	2.0	7.7	60.9
Groups A & E			
Pacific sanddab	5.0	20.2	20.2
Yellowchin sculpin	1.7	10.4	30.7
Dover sole	5.0	10.1	40.8
Halfbanded rockfish	2.4	7.6	48.4
Shortspine combfish	2.1	5.9	54.3
Groups A & H			
Pacific sanddab	2.8	17.5	17.5
Dover sole	3.2	10.5	28.0
Shortspine combfish	2.7	6.9	34.8
Longspine combfish	2.2	6.8	41.6
California lizardfish	0.9	6.7	48.4
Groups A & J			
Halfbanded rockfish	12.0	19.2	19.2
Pacific sanddab	2.0	9.6	28.8
Dover sole	1.4	7.3	36.1
Longspine combfish	1.3	5.7	41.8
Yellowchin sculpin	0.8	5.0	46.8
Groups B & J			
Plainfin midshipman	12.8	25.0	25.0
Dover sole	4.2	11.0	35.9
Bigfin eelpout	22.9	4.9	40.9
Pacific sanddab	1.9	4.6	45.5
Gulf sanddab	3.0	4.3	49.7
Groups C & J			
Halfbanded rockfish	23.1	18.7	18.7
Squarespot rockfish	10.6	11.0	29.7
Pacific sanddab	3.8	8.9	38.6
Vermilion rockfish	23.1	5.9	44.5
Stripetail rockfish	5.9	5.1	49.6
Groups D & B			
Stripetail rockfish	8.4	14.2	14.2
Pacific sanddab	2.7	11.2	25.3
Plainfin midshipman	2.0	10.0	35.3
Longfin sanddab	9.1	9.0	44.3
Yellowchin sculpin	2.8	8.2	52.5

Appendix E.6 *continued*

Species	Average Dissimilarity/ Standard Deviation	Percent Contribution	Cumulative Percent Contribution
Groups D & C			
Stripetail rockfish	6.6	12.7	12.7
Longfin sanddab	9.1	9.3	22.0
Pacific sanddab	2.1	8.6	30.7
Yellowchin sculpin	2.8	8.6	39.3
Halfbanded rockfish	28.7	8.6	47.8
Groups D & E			
Stripetail rockfish	10.0	19.5	19.5
Longfin sanddab	8.9	11.3	30.8
Pacific sanddab	1.5	7.7	38.4
Plainfin midshipman	1.5	5.9	44.4
Yellowchin sculpin	1.3	5.1	49.5
Groups D & H			
Stripetail rockfish	4.0	15.0	15.0
Longfin sanddab	6.5	9.5	24.6
Yellowchin sculpin	2.3	7.9	32.5
Pacific sanddab	1.4	7.4	39.9
Plainfin midshipman	1.4	5.2	45.0
Groups D & J			
Stripetail rockfish	4.4	16.9	16.9
Pacific sanddab	3.4	16.9	33.8
Longfin sanddab	4.1	8.5	42.3
Yellowchin sculpin	2.0	7.8	50.0
Plainfin midshipman	1.9	7.3	57.3
Groups E & B			
Plainfin midshipman	16.6	20.9	20.9
Yellowchin sculpin	1.7	8.5	29.4
Pacific sanddab	1.9	7.6	37.1
Dover sole	2.0	5.3	42.4
Shortspine combfish	2.2	4.7	47.2
Groups E & C			
Halfbanded rockfish	5.9	16.0	16.0
Squarespot rockfish	15.2	11.9	27.9
Yellowchin sculpin	1.7	9.3	37.2
Dover sole	3.0	6.5	43.7
Vermilion rockfish	15.2	6.1	49.8
Groups E & H			
Halfbanded rockfish	1.0	9.9	9.9
Yellowchin sculpin	1.6	9.1	19.0
Pacific sanddab	1.4	8.2	27.2
California lizardfish	0.9	7.8	35.0
Dover sole	1.4	4.6	39.6

Appendix E.6 *continued*

Species	Average Dissimilarity/ Standard Deviation	Percent Contribution	Cumulative Percent Contribution
Groups E & J			
Pacific sanddab	3.0	17.6	17.6
Yellowchin sculpin	1.5	10.1	27.7
Dover sole	1.9	7.2	34.9
Shortspine combfish	2.3	7.1	42.0
Halfbanded rockfish	1.1	4.3	46.3
Groups F & A			
Pacific sanddab	5.0	23.5	23.5
Dover sole	3.2	10.7	34.2
Halfbanded rockfish	3.4	8.1	42.3
Yellowchin sculpin	1.7	7.8	50.1
Stripetail rockfish	1.6	6.4	56.5
Groups F & B			
Plainfin midshipman	3.3	18.2	18.2
Pacific sanddab	3.3	12.8	31.0
Yellowchin sculpin	1.7	7.1	38.1
Longfin sanddab	1.6	5.1	43.1
Gulf sanddab	4.8	4.6	47.8
Groups F & C			
Halfbanded rockfish	6.4	14.7	14.7
Squarespot rockfish	14.3	10.0	24.7
Pacific sanddab	2.4	8.4	33.1
Dover sole	2.4	7.2	40.3
Yellowchin sculpin	1.7	6.7	47.0
Groups F & D			
Stripetail rockfish	3.3	16.6	16.6
Longfin sanddab	2.0	7.6	24.2
Plainfin midshipman	1.4	6.7	30.9
Yellowchin sculpin	1.6	6.4	37.2
Dover sole	1.5	5.7	43.0
Groups F & E			
Pacific sanddab	1.4	8.9	8.9
Stripetail rockfish	1.6	7.8	16.7
Yellowchin sculpin	1.4	7.6	24.3
Longfin sanddab	1.6	7.1	31.4
Plainfin midshipman	1.3	5.4	36.9
Groups F & G			
Longspine combfish	1.4	9.2	9.2
Pacific sanddab	1.4	8.2	17.4
Halfbanded rockfish	1.3	7.2	24.6
Dover sole	1.4	6.5	31.1
Yellowchin sculpin	1.2	6.4	37.5

Appendix E.6 *continued*

Species	Average Dissimilarity/ Standard Deviation	Percent Contribution	Cumulative Percent Contribution
Groups F & H			
Halfbanded rockfish	1.1	9.7	9.7
Pacific sanddab	1.5	8.5	18.1
California lizardfish	0.9	6.7	24.8
Yellowchin sculpin	1.5	6.6	31.4
Shortspine combfish	2.2	5.8	37.2
Groups F & J			
Pacific sanddab	3.9	21.8	21.8
Dover sole	1.8	8.3	30.1
Yellowchin sculpin	1.3	7.1	37.2
Stripetail rockfish	1.5	6.8	44.0
Plainfin midshipman	1.3	6.0	50.0
Groups G & A			
Pacific sanddab	5.0	24.4	24.4
Dover sole	5.0	13.1	37.5
Longspine combfish	1.4	9.0	46.4
Yellowchin sculpin	1.2	6.2	52.7
Slender sole	1.3	5.1	57.7
Groups G & B			
Plainfin midshipman	5.2	16.6	16.6
Pacific sanddab	3.7	16.1	32.7
Halfbanded rockfish	1.5	6.3	39.0
Yellowchin sculpin	1.2	6.0	45.0
Longspine combfish	1.4	5.9	50.9
Groups G & C			
Pacific sanddab	2.9	12.8	12.8
Dover sole	4.1	10.9	23.7
Squarespot rockfish	14.5	9.2	32.8
Halfbanded rockfish	2.1	8.5	41.3
Longspine combfish	1.3	6.9	48.2
Groups G & D			
Stripetail rockfish	4.3	14.9	14.9
Longfin sanddab	4.9	9.7	24.6
Dover sole	2.6	8.7	33.3
Longspine combfish	1.4	6.2	39.4
Yellowchin sculpin	1.7	5.9	45.3
Groups G & E			
Pacific sanddab	1.8	13.2	13.2
Longspine combfish	1.3	9.1	22.3
Dover sole	1.7	7.8	30.1
Yellowchin sculpin	1.4	7.0	37.1
Halfbanded rockfish	1.2	6.1	43.2

Appendix E.6 *continued*

Species	Average Dissimilarity/ Standard Deviation	Percent Contribution	Cumulative Percent Contribution
Groups G & H			
Pacific sanddab	1.5	12.3	12.3
Longspine combfish	1.5	7.5	19.7
Halfbanded rockfish	0.9	7.2	26.9
California lizardfish	0.9	6.7	33.6
Yellowchin sculpin	1.2	6.6	40.2
Groups G & J			
Pacific sanddab	4.2	21.4	21.4
Dover sole	3.2	10.6	32.1
Longspine combfish	1.3	7.8	39.8
Halfbanded rockfish	1.5	6.8	46.7
Yellowchin sculpin	1.1	5.4	52.0
Groups H & B			
Plainfin midshipman	5.3	18.9	18.9
Halfbanded rockfish	1.3	10.0	28.8
Pacific sanddab	1.4	8.1	36.9
Shortspine combfish	2.7	6.1	43.0
California lizardfish	0.9	6.0	49.0
Groups H & C			
Squarespot rockfish	7.7	10.4	10.4
Halfbanded rockfish	1.6	9.5	19.9
Dover sole	2.3	7.7	27.6
California lizardfish	0.9	6.4	34.0
Pacific sanddab	1.2	6.2	40.1
Groups H & J			
Pacific sanddab	1.9	13.0	13.0
Halfbanded rockfish	1.4	11.2	24.2
Dover sole	1.9	7.1	31.3
Shortspine combfish	2.7	6.9	38.2
California lizardfish	0.9	6.7	44.9
Groups I & A			
Pacific sanddab	2.7	15.1	15.1
Halfbanded rockfish	2.3	10.5	25.6
Dover sole	2.9	9.9	35.4
Plainfin midshipman	1.0	8.0	43.4
Stripetail rockfish	0.9	5.4	48.9
Groups I & B			
Plainfin midshipman	3.9	19.8	19.8
Dover sole	2.6	7.0	26.8
Longfin sanddab	2.0	5.3	32.0
Longspine combfish	2.8	4.9	37.0
Gulf sanddab	3.9	4.7	41.6

Appendix E.6 *continued*

Species	Average Dissimilarity/ Standard Deviation	Percent Contribution	Cumulative Percent Contribution
Groups I & C			
Halfbanded rockfish	4.6	16.4	16.4
Squarespot rockfish	9.0	11.3	27.6
Vermilion rockfish	9.0	5.8	33.5
Greenblotched rockfish	2.9	5.6	39.1
Longfin sanddab	2.0	5.4	44.5
Groups I & D			
Stripetail rockfish	3.3	16.5	16.5
Pacific sanddab	1.9	12.7	29.2
Yellowchin sculpin	2.0	7.6	36.8
Longfin sanddab	2.4	6.7	43.5
Plainfin midshipman	1.4	6.3	49.9
Groups I & E			
Pacific sanddab	1.4	10.7	10.7
Yellowchin sculpin	1.3	9.0	19.7
Longfin sanddab	2.0	7.5	27.1
Plainfin midshipman	0.9	6.0	33.1
Stripetail rockfish	0.8	5.4	38.5
Groups I & F			
Pacific sanddab	1.7	15.5	15.5
Plainfin midshipman	1.1	7.2	22.7
Stripetail rockfish	1.3	6.9	29.6
Yellowchin sculpin	1.2	6.7	36.3
Dover sole	1.4	5.6	41.9
Groups I & G			
Pacific sanddab	2.2	16.9	16.9
Longspine combfish	1.4	9.2	26.1
Dover sole	2.1	8.1	34.2
Halfbanded rockfish	1.2	5.7	39.9
Yellowchin sculpin	1.1	5.2	45.1
Groups I & H			
Halfbanded rockfish	1.1	9.4	9.4
Pacific sanddab	1.3	9.1	18.6
California lizardfish	0.9	6.8	25.3
Longspine combfish	1.7	5.8	31.2
Longfin sanddab	1.8	5.2	36.4
Groups I & J			
Pacific sanddab	1.7	10.8	10.8
Plainfin midshipman	1.0	8.0	18.8
Stripetail rockfish	1.0	7.2	26.0
Dover sole	1.4	6.1	32.1
Longfin sanddab	1.3	5.3	37.4

Appendix E.7

List of megabenthic invertebrate taxa captured during 2010 at PLOO trawl stations. Data are number of individuals (*n*). Taxonomic arrangement from SCAMIT 2008.

Taxon/Species					*n*
SILICEA					
	DEMOSPONGIAE				
		Hadromerida			
			Suberitidae		
				Suberites latus	6
CNIDARIA					
	ANTHOZOA				
		Alcyonacea			
			Plexauridae		
				Thesea sp B	6
		Pennatulacea			
			Virgulariidae		
				Acanthoptilum sp	888
		Actiniaria			
			Metridiidae		
				Metridium farcimen	1
MOLLUSCA					
	GASTROPODA				
		Vetigastropoda			
			Calliostomatidae		
				Calliostoma turbinum	1
		Hypsogastrodpoda			
			Ovulidae		
				Neosimnia barbarensis	32
			Naticidae		
				Euspira draconis	1
			Turridae		
				Antiplanes catalinae	1
			Cancellariidae		
				Cancellaria crawfordiana	1
		Opisthobranchia			
			Philinidae		
				Philine alba	3
				Philine auriformis	13
			Pleurobranchidae		
				Pleurobranchaea californica	58
			Dorididae		
				Doris montereyensis	1
			Discodorididae		
				Platydoris macfarlandi	1
			Arminidae		
				Armina californica	6
			Tritoniidae		
				Tritonia diomedea	2
		Dendronotidae			
				Dendronotus iris	1

Appendix E.7 *continued*

Taxon/Species				n
	CEPHALOPODA			
		Sepiolida		
			Sepiolidae	
			Rossia pacifica	6
		Octopoda		
			Octopodidae	
			Octopus rubescens	10
ANNELIDA				
	POLYCHAETA			
		Aciculata		
			Polynoidae	
			Arctonoe pulchra	2
ARTHROPODA				
	MALACOSTRACA			
		Stomatopoda		
			Hemisquillidae	
			Hemisquilla californiensis	1
		Isopoda		
			Cymothoidae	
			Elthusa vulgaris	3
		Decapoda		
			Sicyoniidae	
			Sicyonia ingentis	10
			Crangonidae	
			Crangon alaskensis	4
			Metacrangon spinosissma	1
			Calappidae	
			Platymera gaudichaudii	4
			Diogenidae	
			Paguristes bakeri	5
			Paguristes turgidus	1
			Epialtidae	
			Loxorhynchus grandis	2
ECHINODERMATA				
	CRINOIDEA			
		Comatulida		
			Antedonidae	
			Florometra serratissima	1
	ASTEROIDEA			
		Paxillosida		
			Luidiidae	
			Luidia armata	8
			Luidia asthenosoma	18
			Luidia foliolata	17
			Astropectinidae	
			Astropecten ornatissimus	1
			Astropecten verrilli	23

Appendix E.7 *continued*

Taxon/Species				*n*
	Valvatida			
		Odontasteridae		
			Odontaster crassus	1
OPHIUROIDEA				
	Ophiurida			
		Ophiactidae		
			Ophiopholis bakeri	1
		Ophiuridae		
			Ophiura luetkenii	146
ECHINOIDEA				
	Temnopleuroida			
		Toxopneustidae		
			Lytechinus pictus	17,723
	Echinoida			
		Strongylocentrotidae		
			Strongylocentrotus fragilis	523
	Spatangoida			
		Spatangidae		
			Spatangus californicus	1
HOLOTHUROIDEA				
	Aspidochirotida			
		Stichopodidae		
			Parastichopus californicus	28

This page intentionally left blank

Appendix E.8

Summary of total abundance by species and station for megabenthic invertebrates at the PLOO trawl stations during 2010.

Species	January 2010						Species Abundance by Survey
	SD7	SD8	SD10	SD12	SD13	SD14	
Lytechinus pictus	1320	1100	2508	3218	1035	617	9798
Acanthoptilum sp	10	2	2	215	59	53	341
Strongylocentrotus fragilis					1	39	40
Ophiura luetkenii	3	2	1	5	17	6	34
Parastichopus californicus	5	4	2	2	3		16
Astropecten verrilli		1	5	1			7
Pleurobranchaea californica	4	2					6
Crangon alaskensis	3			1			4
Thesea sp B		1		3			4
Platymera gaudichaudii			2			1	3
Sicyonia ingentis	3						3
Armina californica			2				2
Luidia armata					1	1	2
Octopus rubescens	2						2
Paguristes bakeri		2					2
Suberites latus					1	1	2
Tritonia diomedea		1	1				2
Arctonoe pulchra				1			1
Florometra serratissima			1				1
Hemisquilla californiensis		1					1
Loxorhynchus grandis			1				1
Luidia asthenosoma			1				1
Luidia foliolata						1	1
Neosimnia barbarensis				1			1
Ophiopholis bakeri			1				1
Paguristes turgidus			1				1
Spatangus californicus	1						1
Winter Total	1351	1116	2528	3447	1117	719	10,278

Appendix E.8 *continued*

Species	July 2010 SD7	SD8	SD10	SD12	SD13	SD14	Species Abundance by Survey
Lytechinus pictus	2598	1405	2275	673	646	328	7925
Acanthoptilum sp	4		24	336	143	40	547
Strongylocentrotus fragilis					87	396	483
Ophiura luetkenii	16	2	10	6	49	29	112
Pleurobranchaea californica	8	4	4	10	10	16	52
Neosimnia barbarensis	1			18	9	3	31
Luidia asthenosoma			5		9	3	17
Astropecten verrilli	4		2	7	1	2	16
Luidia foliolata	1	8	5	1	1		16
Philine auriformis	7		2	1	2	1	13
Parastichopus californicus	3	3	3	2	1		12
Octopus rubescens	2	1	1	1	2	1	8
Sicyonia ingentis	1		2	4			7
Luidia armata	3	3					6
Rossia pacifica	2	4					6
Armina californica					4		4
Suberites latus		1	1	2			4
Elthusa vulgaris	2			1			3
Paguristes bakeri		1	1	1			3
Philine alba		3					3
Thesea sp B			2				2
Antiplanes catalinae				1			1
Arctonoe pulchra			1				1
Astropecten ornatissimus					1		1
Calliostoma turbinum				1			1
Cancellaria crawfordiana		1					1
Dendronotus iris					1		1
Doris montereyensis		1					1
Euspira draconis			1				1
Loxorhynchus grandis	1						1
Metacrangon spinosissima	1						1
Metridium farcimen						1	1
Odontaster crassus		1					1
Platydoris macfarlandi				1			1
Platymera gaudichaudii			1				1
Summer Total	2654	1438	2340	1066	966	820	9284

Appendix F

Supporting Data

2010 PLOO Stations

Bioaccumulation of Contaminants in Fish Tissues

Appendix F.1

Lengths and weights of fishes used for each composite sample for the PLOO monitoring program during October 2010. Data are summarized as number of individuals (*n*), minimum, maximum, and mean values.

				Length (cm, size class)			Weight (g)		
Station	**Comp**	**Species**	***n***	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
RF1	1	California scorpionfish	3	21	24	22.3	294	382	327.3
RF1	2	California scorpionfish	3	20	22	20.7	212	338	272.3
RF1	3	California scorpionfish	3	19	22	20.3	204	307	246.0
RF2	1	Vermilion rockfish	3	30	40	34.3	805	1811	1216.3
RF2	2	Mixed rockfish	3	18	31	25.7	125	895	519.3
RF2	3	Mixed rockfish	3	19	35	26.3	137	1325	616.0
Zone 1	1	Pacific sanddab	7	14	22	17.0	41	176	79.7
Zone 1	2	Pacific sanddab	6	15	18	16.7	56	86	73.0
Zone 1	3	Pacific sanddab	3	16	22	18.7	63	197	116.3
Zone 2	1	Pacific sanddab	7	17	20	18.1	55	137	87.6
Zone 2	2	Pacific sanddab	6	17	21	18.5	74	144	103.3
Zone 2	3	Pacific sanddab	6	16	21	17.7	77	145	94.2
Zone 3	1	Pacific sanddab	7	15	20	17.3	56	113	74.9
Zone 3	2	Pacific sanddab	6	17	20	18.3	56	119	85.7
Zone 3	3	Pacific sanddab	7	17	20	18.1	61	119	90.0
Zone 4	1	Pacific sanddab	8	15	18	16.4	44	75	62.1
Zone 4	2	Pacific sanddab	7	15	20	17.1	53	135	79.1
Zone 4	3	Pacific sanddab	7	14	19	16.4	39	108	68.0

This page intentionally left blank

Appendix F.2

Constituents and method detection limits (MDL) for fish tissue samples analyzed for the PLOO monitoring program during October 2010.

Parameter	MDL Liver	MDL Muscle	Parameter	MDL Liver	MDL Muscle
Metals (ppm)					
Aluminum (Al)	3	3	Lead (Pb)	0.2	0.2
Antimony (Sb)	0.2	0.2	Manganese (Mn)	0.1	0.1
Arsenic (As)	0.24	0.24	Mercury (Hg)	0.01	0.01
Barium (Ba)	0.03	0.03	Nickel (Ni)	0.2	0.2
Beryllium (Be)	0.006	0.006	Selenium (Se)	0.06	0.06
Cadmium (Cd)	0.06	0.06	Silver (Ag)	0.05	0.05
Chromium (Cr)	0.1	0.1	Thallium (Tl)	0.4	0.4
Copper (Cu)	0.1	0.1	Tin (Sn)	0.2	0.2
Iron (Fe)	2	2	Zinc (Zn)	0.15	0.15
Chlorinated Pesticides (ppb)					
Hexachlorocyclohexane (HCH)					
HCH, Alpha isomer	24.7	2.47	HCH, Delta isomer	4.53	0.45
HCH, Beta isomer	4.68	0.47	HCH, Gamma isomer	63.40	6.34
Total Chlordane					
Alpha (cis) Chlordane	4.56	0.46	Heptachlor epoxide	3.89	0.39
Cis Nonachlor	4.7	0.47	Oxychlordane	7.77	0.78
Gamma (trans) Chlordane	2.59	0.26	Trans Nonachlor	2.58	0.26
Heptachlor	3.82	0.38			
Total Dichlorodiphenyltrichloroethane (DDT)					
o,p-DDD	2.02	0.2	p,p-DDD	3.36	0.34
o,p-DDE	2.79	0.28	p,p-DDE	2.08	0.21
o,p-DDT	1.62	0.16	p,p-DDT	2.69	0.27
p,-p-DDMU	3.29	0.33			
Miscellaneous Pesticides					
Aldrin	88.10	8.81	Hexachlorobenzene (HCB)	1.32	0.13
Alpha Endosulfan	118	11.80	Mirex	1.49	0.15
Dieldrin	17.10	1.71	Toxaphene	342	34.20
Endrin	14.2	1.42			

Appendix F.2 *continued*

Parameter	MDL Liver	MDL Muscle	Parameter	MDL Liver	MDL Muscle
Polychlorinated Biphenyl Congeners (PCBs) (ppb)					
PCB 28	2.47	0.28	PCB 128	1.23	0.12
PCB 37	2.77	0.25	PCB 138	1.73	0.17
PCB 44	3.65	0.36	PCB 149	2.34	0.23
PCB 49	5.02	0.5	PCB 151	1.86	0.19
PCB 52	5.32	0.53	PCB 153/168	2.54	0.25
PCB 66	2.81	0.28	PCB 156	0.64	0.06
PCB 70	2.49	0.25	PCB 157	2.88	0.29
PCB 74	3.1	0.31	PCB 158	2.72	0.27
PCB 77	2.01	0.2	PCB 167	1.63	0.16
PCB 81	3.56	0.36	PCB 169	2.76	0.28
PCB 87	3.01	0.3	PCB 170	1.23	0.12
PCB 99	3.05	0.3	PCB 177	1.91	0.19
PCB 101	4.34	0.43	PCB 18	2.86	0.29
PCB 105	2.29	0.23	PCB 180	2.58	0.26
PCB 110	2.5	0.25	PCB 183	1.55	0.15
PCB 114	3.15	0.31	PCB 187	2.5	0.25
PCB 118	2.06	0.21	PCB 189	1.78	0.18
PCB 119	2.39	0.24	PCB 194	1.14	0.11
PCB 123	2.64	0.26	PCB 201	2.88	0.29
PCB 126	1.52	0.15	PCB 206	1.28	0.13

Appendix F.3

Summary of constituents that make up total DDT and total PCB in each composite sample collected as part of the PLOO monitoring program during October 2010.

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2010-4	RF1	1	California scorpionfish	Muscle	DDT	p,p-DDE	9.8	ppb
2010-4	RF1	1	California scorpionfish	Muscle	DDT	p,-p-DDMU	0.5	ppb
2010-4	RF1	1	California scorpionfish	Muscle	PCB	PCB 66	0.2	ppb
2010-4	RF1	1	California scorpionfish	Muscle	PCB	PCB 99	0.5	ppb
2010-4	RF1	1	California scorpionfish	Muscle	PCB	PCB 101	0.5	ppb
2010-4	RF1	1	California scorpionfish	Muscle	PCB	PCB 118	0.6	ppb
2010-4	RF1	1	California scorpionfish	Muscle	PCB	PCB 138	0.8	ppb
2010-4	RF1	1	California scorpionfish	Muscle	PCB	PCB 153/168	1.6	ppb
2010-4	RF1	1	California scorpionfish	Muscle	PCB	PCB 187	0.5	ppb
2010-4	RF1	2	California scorpionfish	Muscle	DDT	p,p-DDE	1.7	ppb
2010-4	RF1	2	California scorpionfish	Muscle	PCB	PCB 138	0.3	ppb
2010-4	RF1	2	California scorpionfish	Muscle	PCB	PCB 153/168	0.7	ppb
2010-4	RF1	3	California scorpionfish	Muscle	DDT	p,p-DDE	1.6	ppb
2010-4	RF1	3	California scorpionfish	Muscle	PCB	PCB 118	0.7	ppb
2010-4	RF1	3	California scorpionfish	Muscle	PCB	PCB 128	0.5	ppb
2010-4	RF1	3	California scorpionfish	Muscle	PCB	PCB 138	0.9	ppb
2010-4	RF1	3	California scorpionfish	Muscle	PCB	PCB 149	0.4	ppb
2010-4	RF1	3	California scorpionfish	Muscle	PCB	PCB 153/168	1.6	ppb
2010-4	RF1	3	California scorpionfish	Muscle	PCB	PCB 156	0.7	ppb
2010-4	RF1	3	California scorpionfish	Muscle	PCB	PCB 157	0.7	ppb
2010-4	RF1	3	California scorpionfish	Muscle	PCB	PCB 158	0.5	ppb
2010-4	RF1	3	California scorpionfish	Muscle	PCB	PCB 167	0.5	ppb
2010-4	RF1	3	California scorpionfish	Muscle	PCB	PCB 180	0.9	ppb
2010-4	RF1	3	California scorpionfish	Muscle	PCB	PCB 187	0.7	ppb
2010-4	RF1	3	California scorpionfish	Muscle	PCB	PCB 194	0.9	ppb
2010-4	RF2	1	Vermilion rockfish	Muscle	DDT	o,p-DDE	0.3	ppb
2010-4	RF2	1	Vermilion rockfish	Muscle	DDT	p,p-DDD	0.4	ppb
2010-4	RF2	1	Vermilion rockfish	Muscle	DDT	p,p-DDE	4.1	ppb
2010-4	RF2	1	Vermilion rockfish	Muscle	DDT	p,-p-DDMU	0.8	ppb
2010-4	RF2	1	Vermilion rockfish	Muscle	PCB	PCB 138	0.5	ppb
2010-4	RF2	1	Vermilion rockfish	Muscle	PCB	PCB 149	0.4	ppb
2010-4	RF2	1	Vermilion rockfish	Muscle	PCB	PCB 153/168	0.9	ppb
2010-4	RF2	2	Mixed Rockfish	Muscle	DDT	p,p-DDD	0.5	ppb
2010-4	RF2	2	Mixed Rockfish	Muscle	DDT	p,p-DDE	1.3	ppb
2010-4	RF2	2	Mixed Rockfish	Muscle	PCB	PCB 153/168	0.3	ppb
2010-4	RF2	3	Mixed Rockfish	Muscle	DDT	p,p-DDD	0.3	ppb
2010-4	RF2	3	Mixed Rockfish	Muscle	DDT	p,p-DDE	4.7	ppb
2010-4	RF2	3	Mixed Rockfish	Muscle	PCB	PCB 118	0.5	ppb
2010-4	RF2	3	Mixed Rockfish	Muscle	PCB	PCB 138	0.5	ppb
2010-4	RF2	3	Mixed Rockfish	Muscle	PCB	PCB 149	0.4	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2010-4	RF2	3	Mixed Rockfish	Muscle	PCB	PCB 153/168	1.1	ppb
2010-4	Zone 1	1	Pacific sanddab	Liver	DDT	p,p-DDD	7.3	ppb
2010-4	Zone 1	1	Pacific sanddab	Liver	DDT	p,p-DDE	130	ppb
2010-4	Zone 1	1	Pacific sanddab	Liver	DDT	p,-p-DDMU	19	ppb
2010-4	Zone 1	1	Pacific sanddab	Liver	DDT	p,p-DDT	8.5	ppb
2010-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 49	3.7	ppb
2010-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 52	9.1	ppb
2010-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 66	2.3	ppb
2010-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 70	5.8	ppb
2010-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 74	2.2	ppb
2010-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 99	15	ppb
2010-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 101	18	ppb
2010-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 110	14	ppb
2010-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 118	20	ppb
2010-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 128	5	ppb
2010-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 138	23	ppb
2010-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 149	7.5	ppb
2010-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 151	5.3	ppb
2010-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 153/168	43	ppb
2010-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 180	17	ppb
2010-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 183	4.4	ppb
2010-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 187	16	ppb
2010-4	Zone 1	2	Pacific sanddab	Liver	DDT	p,p-DDD	6.1	ppb
2010-4	Zone 1	2	Pacific sanddab	Liver	DDT	p,p-DDE	71	ppb
2010-4	Zone 1	2	Pacific sanddab	Liver	DDT	p,-p-DDMU	8.7	ppb
2010-4	Zone 1	2	Pacific sanddab	Liver	DDT	p,p-DDT	4.3	ppb
2010-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 49	3.1	ppb
2010-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 52	5.6	ppb
2010-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 66	2.4	ppb
2010-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 70	3.5	ppb
2010-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 74	1.8	ppb
2010-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 99	13	ppb
2010-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 101	19	ppb
2010-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 110	12	ppb
2010-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 118	25	ppb
2010-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 128	4.2	ppb
2010-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 138	24	ppb
2010-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 149	13	ppb
2010-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 151	6.4	ppb
2010-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 153/168	51	ppb
2010-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 180	14	ppb
2010-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 187	16	ppb
2010-4	Zone 1	3	Pacific sanddab	Liver	DDT	o,p-DDE	4	ppb
2010-4	Zone 1	3	Pacific sanddab	Liver	DDT	p,p-DDD	5.9	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2010-4	Zone 1	3	Pacific sanddab	Liver	DDT	p,p-DDE	120	ppb
2010-4	Zone 1	3	Pacific sanddab	Liver	DDT	p,-p-DDMU	18	ppb
2010-4	Zone 1	3	Pacific sanddab	Liver	DDT	p,p-DDT	14	ppb
2010-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 49	3.6	ppb
2010-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 52	5.3	ppb
2010-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 66	2.6	ppb
2010-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 70	3.3	ppb
2010-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 74	1.9	ppb
2010-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 99	15	ppb
2010-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 101	15	ppb
2010-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 110	12	ppb
2010-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 118	21	ppb
2010-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 128	6.5	ppb
2010-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 138	31	ppb
2010-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 149	8.1	ppb
2010-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 151	8	ppb
2010-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 153/168	62	ppb
2010-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 180	18	ppb
2010-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 183	7.1	ppb
2010-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 187	21	ppb
2010-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 194	6	ppb
2010-4	Zone 2	1	Pacific sanddab	Liver	DDT	p,p-DDD	5.2	ppb
2010-4	Zone 2	1	Pacific sanddab	Liver	DDT	p,p-DDE	87	ppb
2010-4	Zone 2	1	Pacific sanddab	Liver	DDT	p,-p-DDMU	8.4	ppb
2010-4	Zone 2	1	Pacific sanddab	Liver	DDT	p,p-DDT	6.3	ppb
2010-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 70	1.7	ppb
2010-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 74	1.4	ppb
2010-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 99	9.4	ppb
2010-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 101	5.5	ppb
2010-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 110	5.5	ppb
2010-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 118	13	ppb
2010-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 128	5.4	ppb
2010-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 138	28	ppb
2010-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 149	3.5	ppb
2010-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 151	4	ppb
2010-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 153/168	43	ppb
2010-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 180	20	ppb
2010-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 187	11	ppb
2010-4	Zone 2	2	Pacific sanddab	Liver	DDT	p,p-DDD	42	ppb
2010-4	Zone 2	2	Pacific sanddab	Liver	DDT	p,p-DDE	50	ppb
2010-4	Zone 2	2	Pacific sanddab	Liver	DDT	p,-p-DDMU	4.3	ppb
2010-4	Zone 2	2	Pacific sanddab	Liver	DDT	p,p-DDT	16	ppb
2010-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 99	4.3	ppb
2010-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 110	4.7	ppb
2010-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 118	5.4	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2010-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 138	6.2	ppb
2010-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 153/168	15	ppb
2010-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 180	4.2	ppb
2010-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 187	6.9	ppb
2010-4	Zone 2	3	Pacific sanddab	Liver	DDT	o,p-DDE	2.4	ppb
2010-4	Zone 2	3	Pacific sanddab	Liver	DDT	p,p-DDD	5.8	ppb
2010-4	Zone 2	3	Pacific sanddab	Liver	DDT	p,p-DDE	120	ppb
2010-4	Zone 2	3	Pacific sanddab	Liver	DDT	p,-p-DDMU	16	ppb
2010-4	Zone 2	3	Pacific sanddab	Liver	DDT	p,p-DDT	7.6	ppb
2010-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 49	3.25	ppb
2010-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 52	4.05	ppb
2010-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 66	2.2	ppb
2010-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 74	1.4	ppb
2010-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 99	8.3	ppb
2010-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 101	8.4	ppb
2010-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 105	3.45	ppb
2010-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 110	5.9	ppb
2010-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 118	11.5	ppb
2010-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 128	3.45	ppb
2010-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 138	17.5	ppb
2010-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 149	6.55	ppb
2010-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 151	3.95	ppb
2010-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 153/168	30.5	ppb
2010-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 180	11.5	ppb
2010-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 187	9.9	ppb
2010-4	Zone 3	1	Pacific sanddab	Liver	DDT	p,p-DDD	5.8	ppb
2010-4	Zone 3	1	Pacific sanddab	Liver	DDT	p,p-DDE	94	ppb
2010-4	Zone 3	1	Pacific sanddab	Liver	DDT	p,-p-DDMU	13	ppb
2010-4	Zone 3	1	Pacific sanddab	Liver	DDT	p,p-DDT	8	ppb
2010-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 49	3.4	ppb
2010-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 52	4.3	ppb
2010-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 66	3	ppb
2010-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 70	2.4	ppb
2010-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 74	1.7	ppb
2010-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 99	16	ppb
2010-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 101	16	ppb
2010-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 105	4.4	ppb
2010-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 110	13	ppb
2010-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 118	22	ppb
2010-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 128	5.6	ppb
2010-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 138	25	ppb
2010-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 149	12	ppb
2010-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 151	6.4	ppb
2010-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 153/168	52	ppb
2010-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 180	12	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2010-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 187	15	ppb
2010-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 194	5.3	ppb
2010-4	Zone 3	2	Pacific sanddab	Liver	DDT	o,p-DDE	2.8	ppb
2010-4	Zone 3	2	Pacific sanddab	Liver	DDT	p,p-DDD	4.1	ppb
2010-4	Zone 3	2	Pacific sanddab	Liver	DDT	p,p-DDE	81	ppb
2010-4	Zone 3	2	Pacific sanddab	Liver	DDT	p,-p-DDMU	11	ppb
2010-4	Zone 3	2	Pacific sanddab	Liver	DDT	p,p-DDT	8	ppb
2010-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 49	3.3	ppb
2010-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 52	5.9	ppb
2010-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 66	2.5	ppb
2010-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 70	3.2	ppb
2010-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 74	2	ppb
2010-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 99	15	ppb
2010-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 101	11	ppb
2010-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 105	6.3	ppb
2010-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 110	11	ppb
2010-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 118	18	ppb
2010-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 128	6.5	ppb
2010-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 138	28	ppb
2010-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 149	6.8	ppb
2010-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 151	7.9	ppb
2010-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 153/168	54	ppb
2010-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 180	17	ppb
2010-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 187	19	ppb
2010-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 194	4.9	ppb
2010-4	Zone 3	3	Pacific sanddab	Liver	DDT	p,p-DDE	75	ppb
2010-4	Zone 3	3	Pacific sanddab	Liver	DDT	p,-p-DDMU	9.9	ppb
2010-4	Zone 3	3	Pacific sanddab	Liver	DDT	p,p-DDT	8.9	ppb
2010-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 49	3.4	ppb
2010-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 52	5.2	ppb
2010-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 66	2.2	ppb
2010-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 70	1.7	ppb
2010-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 74	1.8	ppb
2010-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 99	15	ppb
2010-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 101	11	ppb
2010-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 110	14	ppb
2010-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 118	24	ppb
2010-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 128	6.1	ppb
2010-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 138	29	ppb
2010-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 149	8	ppb
2010-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 151	6.8	ppb
2010-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 153/168	45	ppb
2010-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 180	19	ppb
2010-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 183	5.1	ppb
2010-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 187	20	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2010-4	Zone 4	1	Pacific sanddab	Liver	DDT	o,p-DDE	4.2	ppb
2010-4	Zone 4	1	Pacific sanddab	Liver	DDT	p,p-DDD	9.3	ppb
2010-4	Zone 4	1	Pacific sanddab	Liver	DDT	p,p-DDE	130	ppb
2010-4	Zone 4	1	Pacific sanddab	Liver	DDT	p,-p-DDMU	22	ppb
2010-4	Zone 4	1	Pacific sanddab	Liver	DDT	p,p-DDT	12	ppb
2010-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 49	5	ppb
2010-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 52	7	ppb
2010-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 66	3.2	ppb
2010-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 70	4.3	ppb
2010-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 74	2	ppb
2010-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 99	20	ppb
2010-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 101	20	ppb
2010-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 105	6.3	ppb
2010-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 110	15	ppb
2010-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 118	25	ppb
2010-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 128	6.5	ppb
2010-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 138	34	ppb
2010-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 149	12	ppb
2010-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 151	8.2	ppb
2010-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 153/168	63	ppb
2010-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 180	20	ppb
2010-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 183	5	ppb
2010-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 187	18	ppb
2010-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 194	5.8	ppb
2010-4	Zone 4	2	Pacific sanddab	Liver	DDT	p,p-DDD	8.8	ppb
2010-4	Zone 4	2	Pacific sanddab	Liver	DDT	p,p-DDE	100	ppb
2010-4	Zone 4	2	Pacific sanddab	Liver	DDT	p,-p-DDMU	11	ppb
2010-4	Zone 4	2	Pacific sanddab	Liver	DDT	p,p-DDT	9.6	ppb
2010-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 49	3.7	ppb
2010-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 52	6.2	ppb
2010-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 66	2.6	ppb
2010-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 70	3.3	ppb
2010-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 74	1.6	ppb
2010-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 99	12	ppb
2010-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 101	13	ppb
2010-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 105	4.1	ppb
2010-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 110	9.5	ppb
2010-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 118	16	ppb
2010-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 128	5.7	ppb
2010-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 138	28	ppb
2010-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 149	8.5	ppb
2010-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 151	6.2	ppb
2010-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 153/168	48	ppb
2010-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 180	19	ppb
2010-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 183	5	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2010-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 187	12	ppb
2010-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 194	4.5	ppb
2010-4	Zone 4	3	Pacific sanddab	Liver	DDT	p,p-DDD	3.85	ppb
2010-4	Zone 4	3	Pacific sanddab	Liver	DDT	p,p-DDE	98.5	ppb
2010-4	Zone 4	3	Pacific sanddab	Liver	DDT	p,-p-DDMU	14	ppb
2010-4	Zone 4	3	Pacific sanddab	Liver	DDT	p,p-DDT	7.7	ppb
2010-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 49	2.8	ppb
2010-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 52	3.65	ppb
2010-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 66	2.15	ppb
2010-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 70	11.2	ppb
2010-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 74	1.75	ppb
2010-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 99	12.5	ppb
2010-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 101	11	ppb
2010-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 110	8.2	ppb
2010-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 118	15.5	ppb
2010-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 128	5.45	ppb
2010-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 138	23.5	ppb
2010-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 149	5.85	ppb
2010-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 151	4.7	ppb
2010-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 153/168	45	ppb
2010-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 180	17.5	ppb
2010-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 183	3.15	ppb
2010-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 187	13.5	ppb

This page intentionally left blank